# The promising future of drones in prehospital medical care and its application to battlefield medicine

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**ABSTRACT:** Unmanned aerial vehicles, commonly referred to as drones, have been made widely available in recent years leading to an exponential growth in their roles and applications. The rapidly developing field of medical drones is on the verge of revolutionizing prehospital medicine enabling advanced health care delivery to once-inaccessible patients. The aim of this review is to clarify the basic technical properties of currently available medical drones and review recent advances and their usefulness in military and civilian health care missions. A thorough search was conducted using conventional medical literature databases and nonmedical popular search engines. The results indicate increasingly rapid incorporation of unmanned aerial vehicles into search and rescue missions, telemedicine assignments, medical supply routes, public health surveillance, and disaster management. Medical drones appear to be of great benefit for improving survivability of deployed forces on and off the battlefield. The emerging aerial medical delivery systems appear to provide particularly promising solutions for bridging some of the many serious gaps between third world health care systems and their western counterparts and between major metropolitan centers and distant rural communities. The global nature of drone-based health care delivery needs points to a need for an international effort between collaborating civilian and military medical forces to harness the currently available resources and novel emerging technologies for broader lifesaving capabilities. (*J Trauma Acute Care Surg.* 2019;87: S28–S34. Copyright © 2019 Wolters Kluwer Health, Inc. All rights reserved.)

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**KEY WORDS:** Drones; prehospital care; battlefield medicine; medical supply chain; telemedicine.

The battlefield of the future will present unique challenges and obstacles for the responding medical team. These include the necessity to deploy small teams to austere environments lacking logistic support, loss of aerial supremacy, and the need to execute complex missions in densely populated areas. Unmanned aerial vehicles (UAV) of various configurations may outperform manned platforms and offer new capabilities for such complex scenarios.

Known popularly as “drones,” UAV's have been a part of the modern military arsenal for the last three decades. Initially designed as a fixed-wing aircraft mimicking conventional manned airplanes, drones, in the past, were deployed mainly for reconnaissance missions of long range and duration. Later models were armed, enabling precision strikes at a moment's notice. Although large, military drones have been around for a long time, new miniaturization technologies and the reduced cost of mass-produced electronic components have resulted in great interest also to the civilian sector. These developments have had great impact on the pace of drone design innovations and have resulted in a huge increase in novel applications of relevance to a broad spectrum of activities in our lives.[1] However, the pace of progress in this field has proposed significant challenges for federal and local regulatory agencies who have had to greatly expand their efforts to meet the huge demands of this booming industry.[1]

Unmanned aerial vehicles have been constructed in many different configurations to support a variety of special tasks (Fig. 1). They can either be controlled remotely or operate autonomously. They can carry a wide range of payloads over easy or difficult terrains. There are several classification systems for drones that take into account different aircraft properties. The latter include craft weight, flying altitude, takeoff and landing capabilities and size.[2] Each platform has its technical and operational advantages and disadvantages. Fixed-wing aircraft can reach high altitudes and travel great distances with relatively high speed. However, they require a preexisting runway or a launching platform. Unmanned aerial vehicles resembling helicopters have vertical takeoff and landing (VTOL) capabilities and are easier to navigate in dense, urban environments and even inside buildings. However, their limitations include shorter flying range, lower speed, and relatively smaller payload capacity.

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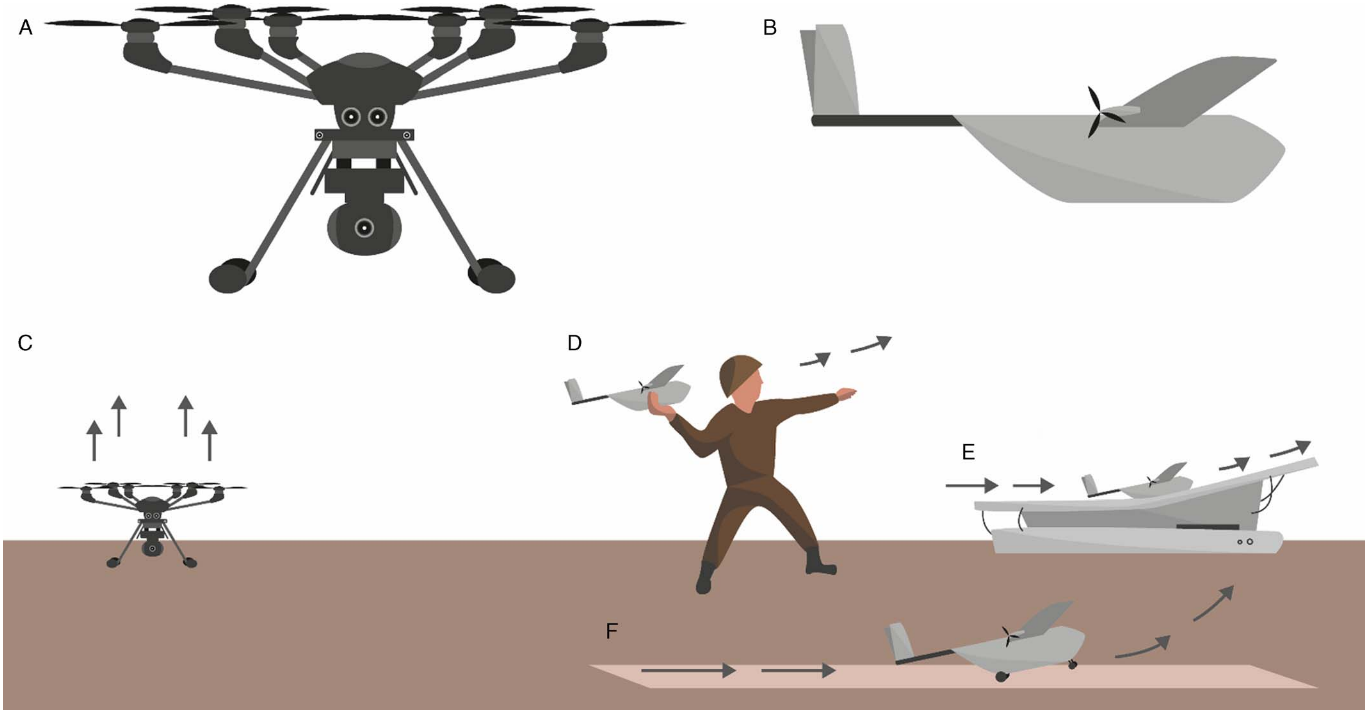


**Figure 1.** Drone configurations and takeoff options—illustrations. *A*, VTOL drone with upward positioned rotors. *B*, Fixed-wing drone resembling an airplane configuration. *C*, VTOL takeoff. *D*, Manual launch of a fixed-wing drone. *E*, Takeoff of a fixed-wing drone from a specialized platform for acceleration of the drone. *F*, Takeoff of a fixed-wing drone from a standard landing strip.

This review focuses on current status and potential roles for drones in military medicine with emphasis on suitability and usefulness for prehospital patient care on the battlefield.

## SEARCH METHODS

An extensive search of the electronic PubMed database (MEDLINE) and Google Scholar was conducted through July 1, 2018, to identify studies with the following search terms: "Unmanned aerial vehicles review," "Drone review," "Health care Drone," "Medical Supply Drone," "Drone rescue," Telemedicine Drone," "Regional blood distribution," "Drone Disaster relief," "Blood unit transportation," "Drone Blood Unit Transportation," or "Drone Blood Component Transportation," "Battlefield medical supply chain," "Battlefield blood usage," "Medical evacuation," "Aerial medical evacuation," and "Trauma Blood." The same keywords were used in the "Google" search engine to find public and commercial information. References of included articles were also screened for relevant studies.

## CURRENT APPLICATIONS OF DRONES IN HEALTH CARE

### Search and Rescue and Forensic Investigation

As mentioned, UAVs were originally used for military purposes, starting as aerial camera carriers for reconnaissance and border patrol. Today, small drones with high-definition cameras are commercially available and are being flown by hobbyists around the world. These distinct capabilities make drones a valuable potential tool for search and rescue missions and transmission of crucial online video of the terrain, including presence of hostile forces. Several research groups around the world are currently working on better understanding these capabilities and how to use them. In a recent case report, Van Tilburg described how a UAV was used to locate, and ultimately rescue, a victim of a rappelling accident in a slot canyon and how it was used in real-time decision making.[3] A Swedish emergency team showed how a similar type of drone was able to locate drowning subjects and emphasized its superiority over other search methods for shortening the time to initiation of cardiopulmonary resuscitation.[4] Researchers in Turkey describe the role for UAVs in searching for injured or missing skiers on the slopes emphasizing its usefulness and limitations for this purpose.[5] Their study was conducted during daytime with good visibility, winds up to 25 km/h, and temperatures that ranged from 1°C to 5°C. Search and rescue missions in the frequently encountered harsher environments would require the sturdier versions of unmanned aircraft with tailored necessary, technical upgrades for similar performance in more difficult conditions.

Forensic investigators rely heavily on photography for on-scene documentation of important details. In an effort to assess the capabilities of UAVs for determining the general layout of crime scenes, including details from images of corpses, Urbanová and Krajsa[6] showed that an aerial drone was a fast and cost-effective method for creation of three-dimensional models of the scene and for searching for scattered body parts. However, in its current configuration, the UAV technology deployed was not of sufficient resolution to identify harder to spot evidence, such as blood spots, and did not substitute for regular crime scene equipment and on-foot investigation by conventional

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methods. Further technical improvements in imaging resolution and remote digital-based technologies are needed to improve the usefulness of unmanned drones in forensic investigations, in general, and at sites of limited access and mass casualty events, in particular.

## Resuscitation and Telemedicine

In prehospital care, timing is crucial. Obstacles, such as traffic or difficult terrain, remain significant challenges for emergency services. The great flexibility and high maneuverability of drones make them highly suitable for reaching emergency cases in a short period. These capabilities have been put to the test for use in real-time telemedicine and rapid transport of resuscitation equipment. In a study by Claesson et al.,[7] a drone-based automated external defibrillator was dispatched from a municipal fire station to local addresses for simulating response to real out-of-the-hospital cardiac arrest cases. After 18 consecutive flights, it was determined retrospectively that the drone arrived more quickly than the original EMS team in all cases with an impressive median reduction in response time of over 16 minutes for a median flight distance of 3.2 km. The Health Integrated Rescue Operations project, performed by telemedicine and aviation experts, configured a response team that consisted of a specially designed, unmanned drone that is rushed to the remote prehospital emergency site.[8] The drone was equipped with cameras and modular kits that included diagnostic equipment, such as an infrared thermometer and easy-to-use electrocardiogram or other lifesaving treatments, such as an epinephrine pen, that can be administered by nonprofessional personnel. The operation calls for a physician to be positioned in a hospital control room for communication with the patient or bystander for interrogation and giving instructions for treatment.

Appropriate triage in mass casualty events is essential for proper incident management. In a recent study involving 40 Canadian paramedic college students randomized to "on-scene" or "UAV"assisted groups, it was determined that the groups made the same decisions in triaging patients of a simulated motor vehicle collision both in day and night time conditions.[9]

Although the current state of the art of UAVs has not yet achieved comprehensive, advanced life support capabilities, certain specific lifesaving assistance has proven to be possible. Additional effort to improve these capabilities, underway in a variety of centers, is of vital importance.

## Crisis Management and Public Health

Mass casualty events, be they a result of natural phenomena or hostile forces, pose major challenges to health services worldwide. Deployed Drones can be of great low-cost assistance to help assess, in a relatively short period, the extent of property damage and integrity of access routes, and provide critical information regarding the number and very preliminary estimates of status of casualties.[10] In addition, a drone-based medical supply delivery network could fulfill an important role in real-time logistic challenges in crisis situations. The successful use of UAVs for such purposes was reported from the 2010 Haiti earthquake, the 2012 hurricane "Superstorm Sandy" (United States, Canada, and Caribbeans), the 2015 cyclone Pam (Vanuatu) and the 2015 "Gorkha" earthquake (Nepal).[11] With drones becoming a standard component of the arsenal of disaster responders, several models have been developed to evaluate efficacy.[12,13]

Many health hazards, such as malaria vector habitats or environmental pollution, can be monitored using sophisticated satellites. However, these are relatively expensive to operate, particularly those that overcome limitations on visibility through the atmosphere, making drones an attractive alternative. Use of drones for supervision of open water sources near rural communities has proven to be very effective, such as for identifying waterbodies suspected to host larvae and, if needed, dusting with larvicide.[14] Chemical spills and nuclear disasters require close monitoring to ensure containment. Such monitoring performed traditionally by air crews or ground teams may result in harmful exposures. Drones fitted with lightweight gamma-spectrometers were used successfully to assess radioactive contamination and effectiveness of decontamination efforts near the Fukushima Daiichi Nuclear Power Plant in Japan. In Italy, drones aided in tracking of heavy-metal ground pollution near agricultural facilities.[15]

## Medical Supplies and Blood Products

Countless health care delivery systems around the world suffer from poor efficiency due to poor local infrastructure. The lack of adequately passable access routes between medical facilities makes it difficult to share scarce resources such as blood products[16,17] or rare or expensive medicines. Drones are a fast and relatively inexpensive method of transportation. They are relatively easy to use and require almost no infrastructure. At present, there are a few enterprises around the globe who have initiated the use of UAVs to assist remote communities. In Rwanda, "Zipline," a US-based startup, operates a working blood and vaccine delivery route to remote clinics in once isolated villages.[18,19] Zipline's new delivery vehicle is an autonomous fixed-wing style airplane that releases the cargo with a paper parachute over the delivery zone. The plane is capable of flying at a top speed of 128 km/h, and a cruising speed of 101 km/h with a round trip range of 160 kilometers carrying up to 1.75 kilos of cargo.[20] In Bhutan, many hard-to-reach mountain communities depend on telemedicine for their primary health care. Matternet, a group pioneering drone delivery network technology, partnered with The United Nations International Children's Emergency Fund (UNICEF) and tested three drones carrying dummy blood samples from a hospital in the city of Thimphu to a remote clinic 15 km away. The same system was tested in Malawi, a country who deals with a heavy human immunodeficiency virus burden, for carrying diagnostic blood samples from a rural clinic to the capital. As a result, children diagnosed with human immunodeficiency virus could enroll much earlier in a treatment program.[21] "Dr. One," a project in Africa sponsored by the United Nations Population Fund, uses drones to provide women in rural Ghana with contraceptives and medicines, cutting transportation time from 2 days to about 30 minutes.[22] According to the "Dr. One" development team, this fixed-wing drone with VTOL capabilities can carry 2 kg of payload to 100 km and each unit saved the Ghana Health services around US $4,129 per year during the pilot[23] (Table 1). The National Aeronautics and Space Administration (NASA) successfully tested drone-based delivery of medicines to a small "pop-up" clinic in rural Virginia using Australian "Flirtey" delivery drones.[24] Langely Cirrus SR22, a remote-controlled airplane, carried the supplies to a local airfield and the Flirtey Hexa-copters bridged the "last mile delivery gap"


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**TABLE 1.** Comparison of Small Medical Supply Delivery Drones' Technical Specifications and Abilities

| | Zipline | DrOne | Matternet | Flirtey | Parcelcopter 4.0 |
|---|---|---|---|---|---|
| Configuration | Fixed wing | Fixed wing | Quad Copter | Hexa Copter | Fixed-wing tilt rotor |
| Maximal speed | 128 km/h | — | 40 km/h | — | 140 km/h |
| Range (for a single battery charge) | 160 km | 100 km | 20 km (1 kg cargo) | 32 km | 65 km |
| Cargo capacity | 1.75 kg | 2 kg | 2.2 kg | 2 kg | 4 kg |
| Takeoff | Runway | VTOL | VTOL | VTOL | VTOL |
| Developers | Zipline and UPS | Drones for development | Matternet | Flirtey | Deutsche Post-DHL |

to the remote clinics.[25] Flirtey drones can carry 2 kg and have a maximal range of 32 km.[26] Lastly, the fourth generation of the "Parcelcopter" by German postal service DHL was tested over a 6-month period delivering medicines to an island in Lake Victoria (Tanzania). The current parcelcopter is a fixed-wing tiltrotor aircraft, able to carry up to 4 kg of supplies and reach a maximal velocity of 140 km/h. It has a flying range of 65 km.[27]

These recent successful aerial medical delivery systems point to a particularly promising solution for bridging some of the many serious gaps between third world health care systems and their western counterparts and between major metropolitan centers and distant rural communities.

Acute shortages can be a daily challenge to blood bank managers, and cooperation between adjacent centers is crucial to maintaining adequate supply.[28] Several studies suggest that the coordination of distribution of blood products during a disaster is no less of a problem.[12] These two issues emphasize the importance of an adequate and efficient system of transportation. Currently, the primary modes of transport for blood products between facilities are ground transportation or manned helicopter flights.[29] Within facilities, blood units are delivered by carrier or by the pneumatic tube system. Studies by Dhar et al. showed that blood units can withstand the forces present in pneumatic tube transfer.[25] However, data regarding the effect of flying blood on the platform of unmanned drones were scant. Amukele et al.[30] tested this with two different types of drones. In the first, blood samples were attached to a fixed-wing aircraft launched by hand toss for landing on its belly. In the second, a multirotor drone carried a standard cooler box filled with packed red blood cells, platelets, and fresh-frozen plasma. The blood components were flown for up to 26 minutes for a distance of up to 20 km. Preflight and postflight measurements of pH, temperature, and signs of hemolysis were recorded. They reported that the integrity of the blood products sent by drone were not inferior to controls sent by conventional land transport.[31] A more recent study by the same group, demonstrated a small but significant change in potassium and glucose levels after longer flight durations of 3 hours.[32] Thus, it appears that drones provide a highly viable alternative for both long distance and interfacility delivery of blood products, but further studies to better refine the usage are needed.

## Medical Evacuation

Shortening the time to evacuation is crucial for increasing the likelihood of survival of trauma patients.[33] Early reports of use of airlifts to transport wounded soldiers come from the Franco-Prussian war.[34] During the past century, prehospital transport time was reduced from 10 hours in World War II to 5 hours in the Korean conflict to 1 hour in the Vietnam conflict, primarily owing to helicopters.[33] Several initiatives originating from commercial companies, medical corps, and research groups are currently developing highly specialized evacuation UAVs, aiming for faster and safer evacuation from the battlefield. An Israeli company (Tactical Robotics, Yavne, Israel) is developing an autonomous medical evacuation drone, designed to evacuate up to two wounded at a time or a 500-kg payload of supplies.[30] It uses inner duct fan technology for propulsion, which has a reduced footprint, allowing it to operate and maneuver in dense urban environments, reaching a speed of 100 knots per hour even under difficult weather conditions with winds of up to 40 knots. Successful experiments of autonomous VTOL and flying over a short obstacle course were conducted, and video demonstrations are available.[35] Another med-evac drone in conception is the DP-14 Hawk (Dragonfly Pictures, Essington, Pennsylvania) which is developed for the US Army in collaboration with NASA and Defense Advance Research Projects Agency (DARPA). The DP-14 has two overhead rotors in a tandem configuration resembling a miniature model of the Ch-47 Chinook. It can function as an autonomous drone with VTOL capabilities and it can carry one casualty or up to 195 kg of supplies at a maximum speed of 105 knots per hour. The DP-14 is also equipped with a special aerial high precision cargo drop mode with an estimated error of less than 3 m.[36]

# DISCUSSION

Unmanned aerial vehicles have the potential to revolutionize battlefield medical care as much as they transformed modern warfare (Fig. 2). In the combat setting, it is estimated that up to 25% of deaths on the battlefield are potentially preventable.[37] Specific lifesaving treatments, such as administration of blood or blood products or advanced airway equipment, have shown to lower mortality in prehospital combat care,[38–40] but are not always readily available in the field due to technical limitations such as fragility of components, short shelf life at room temperatures, and limited carrying capacity. During intense combat, supplies can be exhausted as the number of casualties exceeds the physiological limitations of the medical staff to carry the supplies. These problems are especially exaggerated in the modern battlefield arena where small units are frequently deployed to remote, austere environments. Reliable supply routes are essential to sustain modern combat medicine.[41] To allow early transfusions, the French army is investigating the effect of air-dropping blood products. A recent report shows no significant damage to RBCs.[42] In view of the important advances referred to above, it appears that the time is ripe to form an ever-ready fleet of

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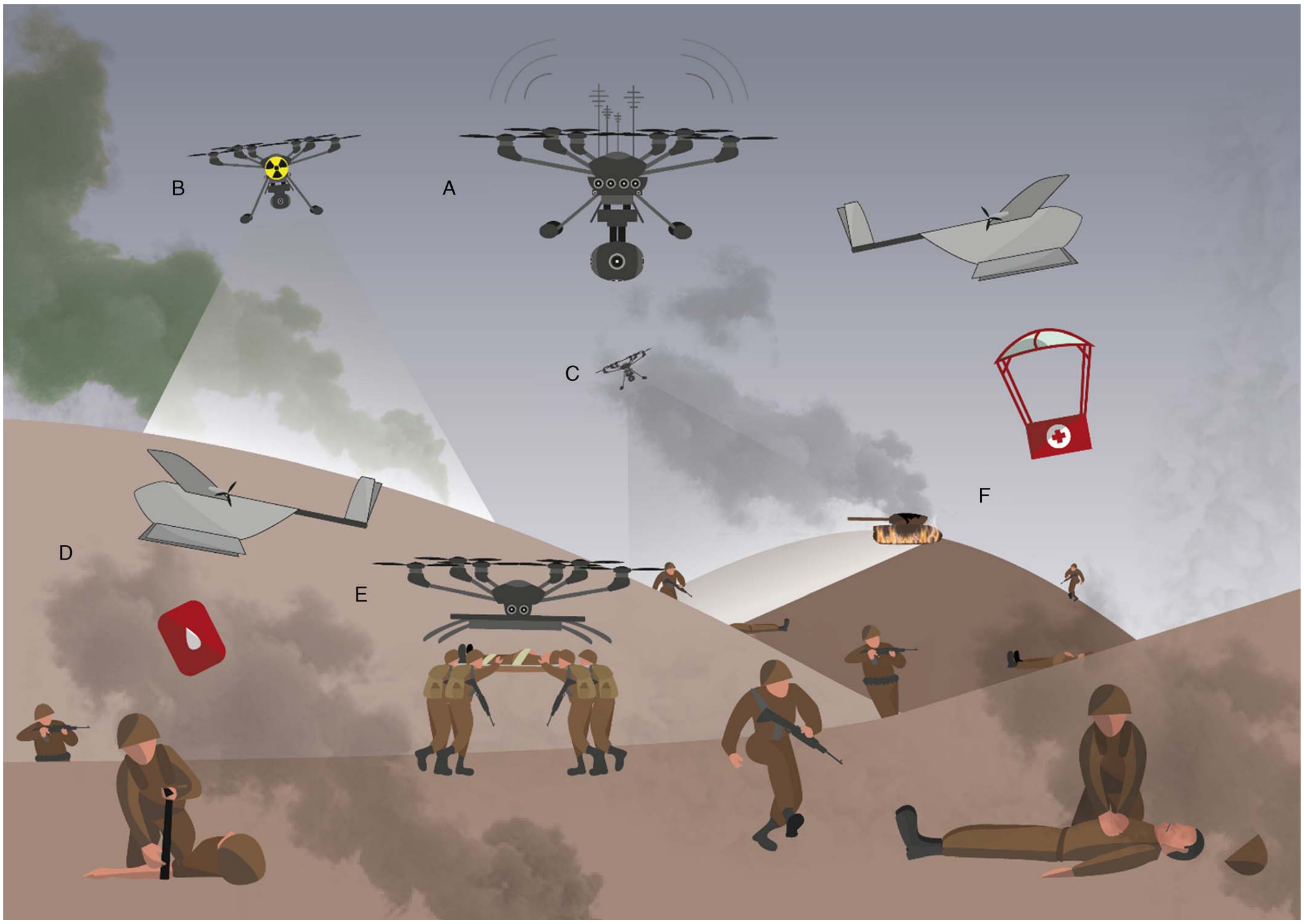


**Figure 2.** Potential uses for drones on the battlefield—illustrations. *A*, Crisis management drone, integrating visual inputs and telemonitoring and mentoring capabilities. *B*, Biochemical hazard monitoring and detection. *C*, Victim search. *D*, Blood products/fragile product drop-off. *E*, Casualty evacuation. *F*, Drop-off of resuscitation equipment and telemedicine capabilities.

medical transport drones to fulfill a role of "on-demand" supply of sensitive medical products to active combat zones.

Aerial evacuations are still performed by manned helicopters with frequently serious risks to the safety of air and medical crews. Evacuation times are determined in large part by the threats posed to the rescue crew, and experience from previous conflicts has emphasized the significant delay in patient transfer to a proper facility.[34] An unmanned option for evacuation of wounded soldiers continues to be actively considered to shorten the waiting time by permitting air travel under increased risks. Furthermore, a combined evacuation method, using unmanned evacuation for the hostile parts of the travel and manned medevac for the rest of the travel might allow faster evacuation with less compromise to medical care.

Mass casualty events can also be managed much more effectively with the field crews receiving valuable, real-time triage information from drone-based imaging. The footage obtained could be used later for debriefing and forensic investigations.

Drones also can be very beneficial to armies under routine, peace-time conditions for telemedicine capabilities and transport of prescription drugs to remote outposts. Clinical samples could also be transported for testing at main centers. Drones could also monitor public health hazards around bases in addition to providing valuable real-time security imaging.

Nonetheless, within these great opportunities lie major challenges, such as vulnerability to cyberattack and airway traffic congestion. Another, particularly major dilemma is whether, and under what circumstances, to permit transport of a trauma patient by UAV without medical accompaniment with no ability to intervene during flight.[43] To address these important issues, NATO set up a dedicated task force with conclusions published in its 2012 comprehensive report, "Safe Ride Standards for Unmanned Medical Evacuation." This report details the minimal standards and life support capabilities required to safely transport trauma patients on unmanned flights. In addition, the report emphasizes the lack of knowledge regarding the physiological tolerance of trauma patients to physical stress such acceleration and deceleration forces involved in such flights.[44]

Although this review is written from a military viewpoint, it is worth highlighting the endless possibilities that drone integration in health systems can contribute to civilian prehospital medicine just as well. A stranded mountaineer could receive critical first aid and automated CPR devices for his injured partner before rescue forces arrive. Paramedics could save precious minutes


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when arriving to the scene of a bus crash if already supplied with an aerial view of the incidence. On a grander scale, national blood banks may operate more efficiently as different centers can be linked to a central depository through a drone blood supply chain. On a similar note, interhospital connectivity would allow for expensive drugs and equipment to be shared between hospitals and enable them to continue to operate despite road closures. Public health would improve because hazards are monitored more closely and responded to more quickly.

In conclusion, it is without question that drone technology is on the verge of revolutionizing prehospital medicine. Its unique capabilities enable delivery, with great speed, of essential lifesaving health care to remote outposts and areas whose access is limited either by natural or hostile events. The extensive experience of the principal developers of flying drones for a wide variety of offensive and defensive combat missions makes the military sector the ideal environment to evaluate the feasibility of new, on-board devices and systems for emergency and routine medical assistance. The global nature of drone-based health care delivery needs points to a requirement for international collaborative efforts between civilian and military medical communities to harness the currently available resources and novel emerging technologies for broader lifesaving capabilities.

## AUTHORSHIP

J.B., S.D.G. and D.N. participated in the review conception. J.B. and D.N. participated in the, literature search and first draft writing. S.D.G., A.F., T.B., H.F., J.C., and E.G. participated in the critical review and complimentary literature search.

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## DISCLOSURE

The authors declare no conflicts of interest.

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