RESUSCITATION PLUS 17 (2024) 100554

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/resuscitation-plus

Review

Challenges & barriers for real-time integration of drones in emergency cardiac care: Lessons from the United States, Sweden, & Canada

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Abstract

Importance: Out-of-hospital cardiac arrest (OHCA) is a leading cause of morbidity and mortality in the US and Europe (~600,000 incident events annually) and around the world (~3.8 million). With every minute that passes without cardiopulmonary resuscitation or defibrillation, the probability of survival decreases by 10%. Preliminary studies suggest that uncrewed aircraft systems, also known as drones, can deliver automated external defibrillators (AEDs) to OHCA victims faster than ground transport and potentially save lives.

Objective: To date, the United States (US), Sweden, and Canada have made significant contributions to the knowledge base regarding AED-equipped drones. The purpose of this Special Communication is to explore the challenges and facilitators impacting the progress of AED-equipped drone integration into emergency medicine research and applications in the US, Sweden, and Canada. We also explore opportunities to propel this innovative and important research forward.

Evidence review: In this narrative review, we summarize the AED-drone research to date from the US, Sweden, and Canada, including the first drone-assisted delivery of an AED to an OHCA. Further, we compare the research environment, emergency medical systems, and aviation regulatory environment in each country as they apply to OHCA, AEDs, and drones. Finally, we provide recommendations for advancing research and implementation of AED-drone technology into emergency care.

Findings: The rates that drone technologies have been integrated into both research and real-life emergency care in each country varies considerably. Based on current research, there is significant potential in incorporating AED-equipped drones into the chain of survival for OHCA emergency response. Comparing the different environments and systems in each country revealed ways that each can serve as a facilitator or barrier to future AED-drone research.

Conclusions and relevance: The US, Sweden, and Canada each offers different challenges and opportunities in this field of research. Together, the international community can learn from one another to optimize integration of AED-equipped drones into emergency systems of care.

Keywords: Automated external defibrillator, Drone, Uncrewed aircraft systems, Emergency medical services, Out-of-hospital cardiac arrest

Introduction

Uncrewed aircraft systems (UAS), also known as drones, are increasingly being used in health care around the world to expand rapid access to emergency care and, ultimately, improve patient outcomes.[1–8] There are multiple applications for drones, including delivery of naloxone for opioid overdose, delivery of vaccines or blood products to rural or remote areas, and transport of laboratory samples for rapid testing.[1,4,9] Despite encouraging results, the rate at which drone technologies have been integrated into real life acute care varies. [10] One area that holds particular promise is the use of drones to deliver automated external defibrillators (AEDs) for patients suffering from out-of-hospital cardiac arrest (OHCA).[5,6,11] To date, researchers in North American and Europe have made significant contributions to the knowledge base regarding AED-equipped drones for OHCA.

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https://doi.org/10.1016/j.resplu.2024.100554

OHCA is a leading cause of morbidity and mortality in the US and Europe (~600,000 incident events annually) and around the world (~3.8 million).[12,13] Despite advances in emergency cardiac care over the last decade,[10] only 7–9% survive with good neurological function.[14] Time-to-treatment plays a pivotal role in survival, with ~10% decrease in survival for every minute of delay to defibrillation.[12,15] Bystander application of an AED before ambulance arrival nearly doubles the chance of survival,[16–25] and cardiac resuscitation systems of care have been developed to increase bystanders' timely access to AEDs. The placement of AEDs in public places including airports, sports facilities, offices, and casinos is associated with increased survival rates. Consequently, fixed, public-access AEDs have been placed in high-traffic areas across both North America and Europe.[26] These programs have increased bystander AED use in public areas (in the US from 2% to 15% and in Canada from 4.0% to 12.1%).[26–28] Based on national Swedish OHCA registry data (2017–2021), bystander AED use prior to emergency medical services (EMS) arrival ranges between 3.7% and 6%.[29] However, even when public access AEDs are nearby, they are often difficult to locate and sometimes inaccessible or improperly maintained. Further, AEDs are often unavailable in residential areas, where most OHCAs occur. [2,30] Despite efforts to increase OHCA survival, overall rates have improved little in the last decade,[29] and new strategies to decrease time to treatment are needed.

Historical OHCA data using geographical information system (GIS) models have demonstrated the potential for delivering AEDs to OHCA sites faster than ground transport or bystander retrieval by strategic placement of drone-AED delivery systems,[31] particularly in rural areas defined as areas with low or geographically diffuse populations.[32,33] Simulations using these systems, although non-integrated with EMS, have further demonstrated the potential for AED-equipped drones to be a cost effective method to improving OHCA survival.[34,35] In this narrative review, we explore the challenges and facilitators to progress in AED-equipped drone integration into emergency medicine applications in the United States (US), Sweden, and Canada. We focused on these countries because they are leading the efforts in AED-delivery yet are at different points regarding the types of research being conducted. We included studies about simulation, modeling, and feasibility research. Based on these collective findings and experiences, we provide recommendations for advancing research and implementation of AED-drone technology into emergency care.

Current research

United States

Research to date on AED-equipped drones has primarily focused on the potential to reduce time to defibrillator access.[3] Drones may be feasible for delivering an AED for OHCA using GIS tools, which could automatically deploy and direct drones to the site of an OHCA.[36] In Salt Lake City, Utah, Pulver et al. (2016) developed an optimized model for an AED-equipped drone network, designed to minimize time to OHCA victims. Investigators found that a drone network could cover 90% of OHCA demand within a minute (flying time), compared to the current 4.3% with existing EMS infrastructure.[37] Bogle et al. (2019) found that if a 500-drone network were deployed from existing EMS facilities across North Carolina, median AED arrival time could be decreased by five minutes, and survival rates could be doubled.[34] In 2020, Rosamond et al. conducted a simulation study involving 35 tests in a community setting and found that a drone was able to autonomously deliver an AED to the site of a simulated OHCA significantly faster than a pedestrian was able to locate and retrieve one, even in areas with a high density of public access AEDs.[2] Participants reported positive interactions with the AED-drone, highlighting that this delivery method allowed them to stay with the victim and continue cardiopulmonary resuscitation (CPR) while waiting for the drone-delivered AED.[38] Together, these findings suggest that drones may provide more timely access to early defibrillation for OHCA compared to a bystander ground search or EMS delivery.

Sweden

In Sweden, 30-day survival from OHCA has ranged 10–11% over the last decade, although AEDs have been widely disseminated.[29] Ambulance response times increased during this period, with a median time from emergency call to arrival of 11 minutes in 2021 (10 minutes if response by first responders such as firefighters or police is included). To study the potential of AED-equipped drones to shorten this delay, Claesson et al. (2016) explored 3,165 historical OHCA-cases from ten rural and ten urban areas in the Stockholm region 2006–2013.[11] Using a GIS model weighted by response time and OHCA incidence, models estimated drones would arrive 19 minutes prior to EMS in 93% of cases in rural areas, although only 3% of all OHCAs occurred in these areas.[11] In urban areas, where 69% of OHCA occurred, 32% of drones would arrive an estimated 1.5 minutes before EMS. Overall, time from dispatch to arrival was faster for the drone compared to EMS (5:21 versus 22:00 minutes; median time benefit 16:39 minutes).[35] Simulations exploring bystanders' experiences of retrieving a drone-delivered AED reported positive user experiences.[39] Researchers also conducted a spatial analysis of drone systems within a 6 km radius for optimal placement across Sweden. Based on 39,246 retrospective EMS-reported OHCA 2010–2018, they found that for an ambulance or AED-equipped drone to reach an OHCA in high-incidence areas (>100 OHCAs over the study period) within eight minutes, 61 drones would be needed. This would cover an estimated 58% of all historical OHCAs, with a median time savings of 5 minutes.[5,40]

During 2019–2020, a system using three AED-equipped drones was developed, integrated with existing EMS-systems, and tested prior to dispatch to real life cases of suspected OHCA.[6] In this first-ever real-life feasibility trial, over four months Schierbeck et al (2022) deployed AED-equipped drones to OHCA in an area covering 80,000 inhabitants. Of 53 alerts for potentially eligible presumptive OHCA, 12 flights were autonomously deployed in advance of EMS. Although there were several false positive events (i.e., ultimately non-OHCA), of 11 final AED deliveries, seven arrived before EMS (64%), with a median time savings of 1:52 minutes. All deliveries were made at a median distance of 9 meters (IQR 7.5–10.5) from the victim or front door. Investigators concluded that that delivery of AEDs using drones was feasible, safe, and resulted in time savings in a real-life setting using a design that was fully-integrated into existing EMS systems.[6] Most recently, investigators conducted a prospective observational study and reported drone delivery of AEDs occurred before ambulances in 37 (67%) cases where drones were deployed, with a median time benefit of 3 minutes 14 seconds (IQR 1 min 42 s-5 min 42 s).[41] Among these, 18 (49%) were true OHCA and a drone-delivered AED was attached in 6 (33%) cases. Two patients had shockable rhythms and were defibrillated; one of these patients survived beyond 30 days.

Canada

The focus of Canadian research has been on geospatial mapping of drone launch sites based on historical OHCA locations, feasibility beyond visual line of sight (BVLOS) drone testing, and qualitative research exploring community response. Through use of mathematical modelling and system optimization, Boutilier et al. (2017) demonstrated that drone delivery could reduce AED arrival time in both rural and urban areas by 50%.[31] In the most urban region, the 90th percentile of AED arrival time was reduced by nearly 7 minutes, and in the most rural region, AED arrival time was reduced by 10.5 minutes.[31] In 2022, Leung et al. explored the integration of drones and selection of drone bases between emergency service stations (i.e., paramedic, fire, police) and the impact on 9-1-1 call-to-arrival time intervals.[42] A total of 1,610 OHCAs were included in the study with a historical median response interval of 6.4 minutes (IQR 5.0–8.6). All drone-integrated response systems significantly reduced the median response interval (range 4.2–5.4 minutes, $p < 0.001$), with grid-based stations using five drones resulting in the lowest response interval (4.2 minutes). Median response times differed between 6–16 seconds between drone base location types.[42] Chu et al. (2021) developed drone dispatch rules based on the difference between a predicted ambulance response time to a calculated drone response time for each OHCA.[43] A total of 3,573 suspected OHCAs were included in the study with median historical ambulance response times of 5.8 minutes (IQR 4.4–7.5). All machine learning-based dispatch rules significantly reduced the median response time to 3.9 minutes (IQR 2.7–5.1) and were non-inferior to universally dispatching drones (all $p < 0.001$) while reducing the number of drone flights by up to 30%.[43] Cheskes et al. (2020) conducted six simulations in two rural communities in Ontario, Canada[44] where a mock 9-1-1 call was placed and an AED-equipped drone and an ambulance were simultaneously dispatched to a predetermined destination. For all simulations, the drone arrived before the ambulance, with time savings of 1.8–8.0 minutes. Investigators concluded that AED drone delivery is both feasible and timely, although EMS integration studies are still needed.

EMS systems, settings, and regulations

The US, Sweden, and Canada differ considerably by geographical setting and population density (Table 1). They also differ in the way that their regulatory agencies, emergency medical response systems, and dispatch systems are organized, funded, and managed. Countries further differ on the rates of CPR and bystander defibrillation. In the US, only 10% of bystander witnessed OHCA involve defibrillation with an AED,[45] compared to 37% of OHCA in Sweden.[46] The likely reasons for these differences include the density and placement of AEDs in the environment, signage identifying the location of an AED, willingness on the part of bystanders to use an AED, and education about AEDs in the general population.

Authorities that regulate aviation in the US (Federal Aviation Administration [FAA]), the European Union (European Aviation Safety Agency [EASA]), and Canada (Transport Canada and NAV Canada) set the technical, safety, and security standards for drones in their respective regions.[1] These agencies are confronted with the challenge of keeping pace with rapid advances in drone technology and new uses of drones while setting regulations to maintain public safety and balance crewed versus uncrewed flight traffic. Given their respective history and organization, each agency approaches these challenges differently.

United States

In the US, the delivery of emergency medical care is fragmented and regionally based. First responders include emergency medical technicians, paramedics, fire fighters, and police. The National Highway Traffic Safety Administration (NHTSA) sets the minimum standards that all EMS providers must meet, and additional regulations are set at the state level; however, EMS providers may be county-based, hospital-based, volunteer rescue squads, not-for-profit, or privately operated to provide out-of-hospital acute medical care and/or transport in specified regions. Prehospital care includes basic (BLS) and advanced life support (ALS) capabilities.[47] BLS providers are the foundation of prehospital management and generally are trained in CPR, select medications given orally, nasally or intramuscularly, and have limited airway management capabilities. ALS providers generally are trained in advanced airway management, advanced cardiac life support, cardiac rhythm interpretation, pediatric life support and intravenous access.[48] Ambulances must be staffed with a minimum of two personnel, but the level of crew varies. EMS medical directors are responsible for overseeing EMS roles in most systems.[49] The 9-1-1 telecommunication and dispatch technologies used within each EMS office also vary, which can also lead to inter-system interoperability challenges. The implementation of drones into these systems has not been researched, although there are private companies attempting integration. Smartphone-based bystander systems (i.e., PulsePoint) are becoming more integrated into communities around the US.[50] These application systems, which alert volunteers trained in CPR to respond to OHCA, have demonstrated clinical benefit in their ability to dispatch responders to OHCA within private residences.[50].

While EMS agencies in the US are regulated at the state level, aviation is federally regulated; thus, there may be conflicts between state and federal regulation of AED-drone systems.[1] Currently, medical drones are permitted only in research, experimental, or highly controlled settings. For example, there are limited uses of drones for search and rescue operations[51] and along pre-approved routes for rapid delivery of laboratory samples.[52] The FAA is in the process of revising restrictions to expand their application beyond these limited settings.[53] A current constraint on the use of medical drones is the FAA requirement that drones remain within the pilot's visual line of sight (Table 2). To fly BVLOS, pilots must obtain additional permission. Another constraint has been restrictions of drone flights over people. While the FAA has updated regulations to allow for more flights over populated areas by requiring additional certification and risk mitigation adaptations (e.g., parachutes, etc.), regulations of operations over people are conservative and waivers are infrequently approved. Further complicating medical drone flights in the US is its increasingly congested airspace.[54,55]

Improved efficiency in the approval process for these types of operations would require finalization of BVLOS requirements and provisions by the FAA. The Aviation Rulemaking Committee on BVLOS submitted a final report including these recommendations to the FAA in 2022, and an official rule is expected within the next few years. For the FAA to modify existing drone flight regulations to enable drone technology to be fully integrated into EMS care, air and ground risk as well as potential lifesaving benefits will need to be more clearly established and balanced.

Table 1 – Overview of national context for drone system implementation.

	US	Canada	Sweden[28]
Population			
Total Population (Jan 1, 2023)	334.2 M	39.6 M	10.5 M
% of Population that is rural (2021)	17.1%	17.8%	11.3%
EMS / First Responder Response			
EMS reported OHCA incidence / 100,000	92.3[76]	96.8	56
Cardiac rhythm VF, VT, or shockable by an AED (in EMS-treated adult OHCA)	16.6%[33]		15.6%
Median EMS dispatch to arrival time (min) (2021)	7.4 (IQR: 5.4–10.3)[76]	7.0 (IQR 5.0–10.0)	10 (IQR: 7–16)
Median First Responder response time (min)(2021)	6.3 (IQR: 5.0–8.5)[76]	6.5 (IQR 5.0–8.5)	NA
% of OHCA for which First Responders arrived on scene in $\leq$ 5 min(2021)	27.8%[76]	NA	NA
Lay Bystander Response			
OHCA witnessed by lay bystander (v. By EMS or not witnessed)	37.1%[14]	51.2%	58.2
Lay bystander defibrillation (non-dispatched) (%)(2021)	10.2%[76]	12.1%	1.7%
Lay bystander CPR (non-dispatched) (%)	40.2%[76]	63.8%	63%
Survival			
Overall survival to hospital admission, %	27.3%[77]	21.9%	21.7% (2019)
Overall survival to hospital discharge, %	9.1%[14]	10.0%	NA
Survival to hospital discharge if witnessed collapse and shockable rhythm, %	29.%	35.0% *2017	39.1% *not witnessed
30 day survival 2021	9.1%[14]	NA	10.8%
Aviation Regulation Agency			
Aviation agency	Federal Aviation Administration (FAA), est. 1958	Transportation Canada's Civil Aviation (TCAA) Directorate, est. 1936	European Union Aviation Safety Agency (EASA), est. 2002
Emergency Response Characteristics			
Dispatch center characteristics	National 9-1-1 program for training and recruitment	Central dispatch with trained dispatchers; Tiered response with BLS and ALS paramedics and fire first responder; Dispatch using MPDS or DPCI 2	National organization Dispatchers with 13 weeks training RN with/without paramedic training
EMS characteristics	EMT/Paramedic ALS providers	Firefighter first responders with BLS and ALS paramedics.	RN with paramedic training ALS providers.

NA = not available; MPDS = medical priority dispatch system; DPCI 2 = dispatch priority card index.

Sweden

Each of Sweden's 21 regions is responsible for providing healthcare to its citizens. The nation's 68 hospitals with an emergency department are publicly financed, and hospital care is limited by law to a maximum cost, including all interventions, to 10 USD per day.[56] Similarly, outpatient care—including ambulance transportation—is limited to 13 USD per trip (230 USD per year).[56] All ambulances are staffed with at least one, regularly two registered nurses (RN) and a paramedic trained to provide advanced life support (ALS) for OHCA. The national emergency medical dispatch center (EMDC, SOS Alarm) answers 1-1-2 emergency calls, provides triage and telecommunicator-CPR, and dispatches EMS. Some regions have an additional or separate emergency medical dispatch center (EMDC) with RNs and physicians to assist with the medical assessment.

The Swedish Transport Agency (STA) communicates and controls regulatory requirements for drone flights on the national level (Table 2). In 2021, regulations were updated to fully comply with Europe's EASA drone regulations.[57] All drones flown in the EU are required to be certified and have CE marking, signifying that products sold in the EU have been assessed to meet high safety, health, and environmental protection requirements and have a designated drone operator responsible throughout the entire flight.

An international first, the EMDC in the Västra Götaland region in 2022 integrated AED-equipped drones by assigning the drone operator a unique dispatch radio number identical to the procedure for dispatching EMS as part of a series of studies with the Karolinska Institute.[5] In these fully-integrated flights, the drone operator is alerted automatically if an emergency call for a suspected OHCA is placed within the administrative area of the drone and within operational hours (i.e., airport and air traffic control are open). The automated dispatch from EMDC triggers the flight planning system and drone to be activated and the drone pilot to call air traffic control (ATC) for clearance.

As part of the studies, all personnel at the EMDC participate in regular e-learning courses addressing OHCA, telecommunicator-CPR, and the drone-delivered AED system, and the study protocol. Regional EMS services are informed of the ongoing studies, retrieve,

Table 2 – Overview of commercial drone categories and core requirements by country.

Variable	US FAA categories		Sweden EASA categories			Canada
Regulation	Part 107	Part 135	Open A1,A2, A3	Specific	Certified (mainly future)	Part – IX, CAR Canadian Aviation Regulations (CARs). Drone must meet the relevant RPAS Safety Assurance requirements to conduct specific advanced operations.
Drone weight (Kg)	<25	Full Aircraft Certification required for any size aircraft	0.25-25	<>25	<>25	≤25
Maximum altitude (meters)	<122	NA	<120	<>120	<>120	≤122
Lines of Sight Rules	VLOS, waiverable	BVLOS	VLOS	BVLOS	BVLOS	BVLOS
Risk level			Low risk	Moderate risk	High risk, complex flying	High, risk (dependent upon air space)
Other	No carriage of hazardous materials, no delivery/dropping of payload. Remote pilot certificate, pilot age >16 years	Commercial Operator – delivery/air taxi, etc.	No carriage of dangerous goods. Drone pilot online certification, pilot age >15 years	Flights in urban areas or dropping material. Remote pilot competency valid for 5 years PDRA or SORA risk assessment. Individual operational authorization document setting out privileges and limits of flight operations.	Similar to flights conducted with manned aircraft, for example taxi flights with passengers or cargo. UAS operator needs air operator approval. Drone must be certified.	Drone flight operations dependent upon basic vs advanced operations regulations. Flights in controlled airspace, over people, within 30 meters of bystanders horizontally, < 3 nautical miles from an airport. < 1 nautical mile from heliport are all considered advanced operations.
Operations over people/moving vehicles	Category 1 Sub .55 pounds (250 grams) Category 2 Collision severity below 25 ft-lbs Category 3 Collision severity below 11 ft-lbs Category 4 Aircraft Certification	Unrestricted				Drones are considered aircraft under the Aeronautics Act and Canadian Aviation Regulations and are therefore prohibited to enter the certain air space without the proper authorizations.
Night Operations	Permitted by Part 107 rules (requires anti-collision lighting)	Unrestricted				With advanced permissions for BVLOS.
Delivery Operations	Not Permitted	Air Carrier Operations				

EASA = European aviation safety agency; FAA = Federal Aviation Administration; BVLOS = Beyond visual line of sight; PDRA = Predefined risk assessment; RPAS = Remote Piloted Aircraft System; SORA = Specific operation risk assessment; VLOS = Visual line of sight.

and bring the drone-delivered AED back to station if found onsite so data can be extracted for research purposes. A thorough Specific Operations Risk Assessment (SORA) analysis prior to initiating flight operations within the controlled airspace mitigates in-air risk. ATC surveillance and redundant systems (i.e., meteorological monitoring, emergency parachute system, flight route planning) mitigate ground risk.

Canada

Transport Canada and NAV Canada, the country's air navigation service providers, both govern the regulatory framework for drone use for time-sensitive medical emergencies in Canada (Table 2). The governing agencies set the rules for use of drones for BVLOS flights, though are dependent on where flights are planned. Flights in uncontrolled air space are generally governed by Transport Canada, while those occurring in controlled air space (within the range of urban settings and airports) are governed by NAV Canada. Both agencies require a detailed stepwise plan based on a SORA for drone use in medical emergencies.[44] All ambulances in Canada are staffed by either primary care, advanced care or critical care paramedics trained in both BLS and ALS for OHCA. First response to OHCA may be provided as well by first responders (fire or police) who are tiered to OHCA calls through the local 911 dispatch center who also provides telecommunicator-CPR. Some regions within Canada have developed local community responder programs which are in their infancy compared to their European counterparts as well as crowdsourcing to OHCA through the use of software applications (i.e., PulsePoint, FIRSTAED, Good Sam). Many of these programs, however, are part of research studies and not yet widely available. To date, no drone program has been integrated with the 9-1-1 dispatch system, although both agencies are heavily engaged in this process. New regulations for low-risk BVLOS are currently under review, with expected approval in 2023, making these types of missions possible.

Challenges to progress

The US remains a world leader in drone technology yet lags behind other nations in use of drones for medical and public health applications.[9] Barriers to integration of drone technology exist at multiple levels, from the regulation of aircraft to research funding complexities including a system that favors low-risk research,[58] physical and communication logistics, and public perception and acceptability.[3] AED usage in the US is further hampered generally by low public knowledge and fear of using a defibrillator in an OHCA event.[59] The US public's view of drones varies by use. Americans tend to be skeptical of commercial and government-based surveillance drones, primarily concerned with overreach of authority, loss of privacy, and safety,[60,61] yet most approve of drone technology for search-and-rescue operations and environmental monitoring.[1] Standardized lights and sirens may help the public recognize AED-drones, though more research is needed to understand public perceptions and acceptability. In Sweden, there have been few negative reports from the public or EMS-services since real-life flight operations started in June 2020. Challenges include better understanding between crewed and uncrewed aircraft systems, optimal design of airspace, conducting operations in uncontrolled airspace, and bystander use of drone-delivered equipment technological support for bystander use of drone-delivered equipment. In Canada, processes to move this technology forward for time sensitive conditions are cumbersome. There is little communication or insight provided to researchers and drone companies from the regulators.

Other potential barriers for full integration of drone technology across countries include connectivity issues that impact global position system (GPS) coordinates, stability of flights, sensing of barriers (e.g., other aircraft), and feasibility to fly in different aerial conditions (e.g., wind, rain).[1] Systems focused on engaging volunteers in OHCA response are associated with greater AED use.[62] Volunteer responder (VR) programs, where dispatched laypersons arrive to a patient prior to EMS and initiate early CPR and defibrillation, have been implemented by EMS agencies around the world.[63,64] However, these programs vary widely by locations, level of participation, and the amount of training and have not yet been studied in the context of AED-drone integration. Currently, VR programs are not integrated with the drone programs in Sweden, US, nor Canada. The focus has been for the bystander/caller to use the AED delivered via drone. Future research focused on the integration and performance of VR with AED-drone programs are needed.

Current knowledge gaps include a lack of real-world data regarding safety, cost-effectiveness, defibrillation rates, and survival rates. Further research that combines with the theoretic work already done is needed about real-life integration of drones in EMS response to OHCA so we can better develop and evaluate the actual clinical and cost-effectiveness of drone-AED delivery systems.[13] We need a better understanding of how to coordinate drone AEDs with emergency dispatch, EMS providers, and potential users in the community. Future work is necessary to guide AED drone placement and design to ensure AEDs are consistently marked and placed in visible locations. Strategies and cues by different subgroups of bystanders (e.g., age, sex) to compare time saving are also needed.[65]

Recommendations

There are lessons learned from progress in the US, Sweden, and Canada for AED-equipped drone in EMS. Drone integration for emergency cardiac care requires a multidisciplinary and coordinated effort that integrates knowledge and expertise from different disciplines. Clinical (i.e., medicine, nursing, EMS), technical (i.e., engineering, industry), and regulatory expertise are essential to advance the field. (Fig. 1) An open and ongoing dialogue between these disciplines is important. To advance this technology into emergency care, we propose key success factors to implementation of AED-drones (Table 3).

While Sweden, Canada, and the US are among those currently leading efforts in the study of drone-AED delivery, important work is also being conducted in the UK[66], Austria,[67] Germany,[68,69] and France.[70] Outside of Europe and North America, research has also begun in Korea.[71,72] There are evolving data from African on drone use for the delivery of emergency medical supplies (e.g., blood samples, medications, vaccines, and diagnostic tools) to remote locations in a timely and cost-effective manner; however, little work has been done in this area yet for AED delivery.[73–75] We support continued international collaboration in the study of ways to best integrate AED-drones in to systems of emergency care for OHCA.

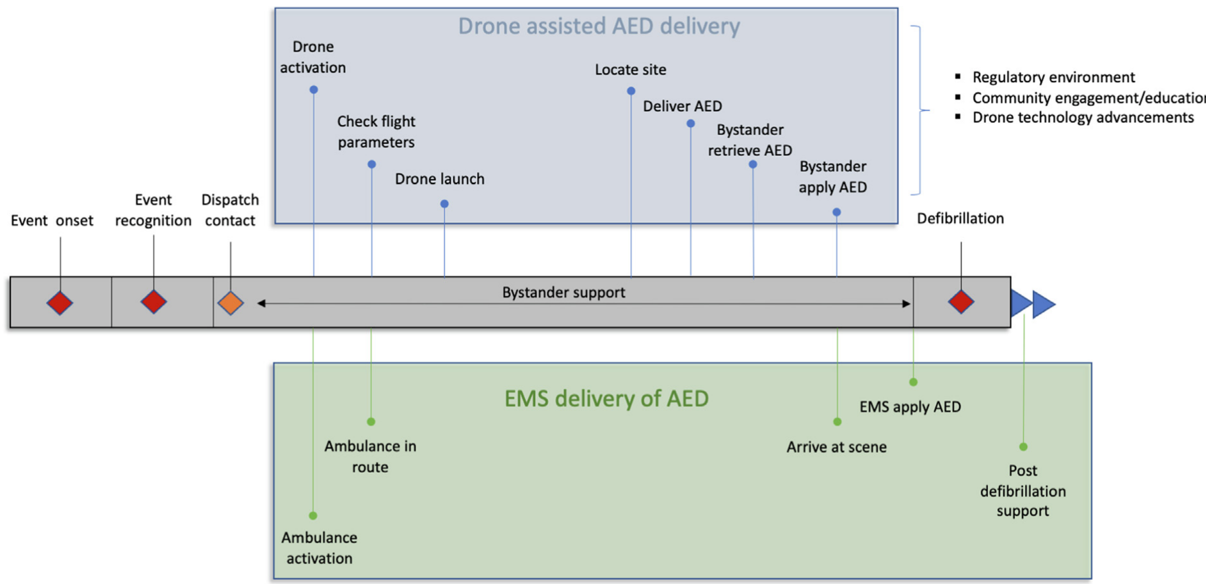

Fig. 1 – Integration of systems for drone-assisted delivery of AED in cardiac arrest.

Table 3 – Success Factors for Implementation of AED-Drones into Emergency Care.
• Identify and analyze historical OHCA data to find optimal locations for AD-drone service. Analyze local conditions for implementation including airspace, EMS-services response times, dispatch center performance etc. • Create a broad-based collaboration between all stakeholders, ensuring each party can contribute to the implementation of drone assisted AED delivery and benefit from its success. • Collaborate with medical, academic and technological partners to design the very specific application of delivering AEDs using drones from technology to bystander interaction. • Engage professional technological partner i.e., drone operator capable of developing a technological platform, including hardware, software applications alongside thorough testing, simulations, and real-life flight operations. • Conduct a thorough, continuous, and transparent risk analysis and provide data to aviation authorities FAA, STA, EASA, Transport Canada, and Nav Canada to underscore the risk-benefit ratio of drone assisted AED delivery. • Extensive flight simulations for optimizing AED-use - VLOS for the specific use-case of delivering AEDs including drone operator, EMDC, ATC, EMS, bystanders and other stakeholders such as police, fire department, city council and more. • Provide early and continuous feedback to the general public of drone service/project alongside working to facilitate an increase of BLS training in the community. • Closely follow all consecutive flights with regards to system performance, adverse events and clinical endpoints and communicate these to stakeholders continuously. • Post-resuscitation provider and patient interactions and experiences with AED-delivery systems. • Legislators/Authorities/Transportation boards (e.g., FAA, EASA, Transport Canada, etc.) should develop a predefined risk assessment protocol with clear criteria specifically for drone delivered AEDs. This will inform future steps and be an initial template for authorities to further develop for other applications.

AEDs. This will inform future steps and be an initial template for authorities to further develop for other applications.

Conclusions

Based on current research, there is significant potential for AED-equipped drones to augment EMS in emergency cardiac care. Given their different research environments, EMS systems, and aviation regulations, the US, Sweden, and Canada each provide different perspectives to drone technology and how it can be integrated to improve access to rapid defibrillation and OHCA outcomes. Each can learn from one another's challenges and facilitators to optimize integration of AED-drone delivery into the chain of survival for OHCA emergency response. Given that survival from OHCA has changed little in the past decade, new approaches are needed, and a multidisciplinary coordinated effort is necessary to advance the promising field of AED-drone delivery.

Funding

This work was supported by the National Center for Advancing Translational Sciences, National Institutes of Health [grant UL1TR002489], the Swedish Heart and Lung Foundation [grant 20200181], the Cardiovascular Network of Canada, and Zoll Medical Inc.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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