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Delivery of Automated External Defibrillators (AED) by Drones: Implications for Emergency Cardiac Care

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Abstract

Purpose of Review—Out-of-hospital cardiac arrest (OHCA) remains a significant health problem in the USA and only 8.6% of victims survive with good neurological function, despite advances in emergency cardiac care. The likelihood of OHCA survival decreases by 10% for every minute without resuscitation.

Recent Findings—Automatic external defibrillators (AEDs) have the potential to save lives yet public access defibrillators are underutilized (< 2% of the time) because they are difficult to locate and rarely available in homes or residential areas, where the majority (70%) of OHCA occur. Even when AEDs are within close proximity (within 100 m), they are not used 40% of the time.

Summary

Unmanned aerial vehicles, or drones, have the potential to deliver AEDs to a bystander and augment emergency medical service (EMS) care. We review the use of drones in medicine, what is currently known, and clinical implications for advancing emergency cardiac care.

Keywords

Sudden cardiac arrest; Automatic external defibrillation; Public access defibrillation; Unmanned aerial vehicles; Drones

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Conflict of Interest

Human and Animal Rights and Informed Consent This article does not contain any studies with animal subjects performed by any of the authors.

Papers of particular interest, published recently, have been highlighted as:

•Of importance

Introduction

Out-of-hospital cardiac arrest (OHCA) remains a significant cause of mortality and morbidity worldwide [1]. Approximately 356,500 people experience OHCA annually in the USA alone, and 60% are treated by emergency medical services (EMS) [2]. Despite advances in emergency cardiac care and technology, overall survival remains low in part due to continued low rates of bystander cardiopulmonary resuscitation (CPR) and barriers to rapid access of life-saving defibrillation, both vital links in the chain of survival [3]. Most sudden cardiac arrests occur outside of the hospital; in OHCAs, survival to hospital discharge is 10.6% and survival with good neurological function is 8.56% [2]. Mounting evidence suggests bystander automatic external defibrillation (AED) is significantly associated with favorable patient outcomes and the likelihood of OHCA survival decreases by 10% for every minute without resuscitation [2]. The survival rate has been reported to triple in cities where bystander defibrillation is provided to patients in cardiac arrest [4, 5]. Bystander application of an AED prior to EMS arrival is associated with nearly doubling the survival of victims suffering OHCA and witnessed OHCA survival rates can reach up to 50% when active citizen cardiopulmonary CPR training programs are coordinated with access to AEDs [6]. OHCA victims who present with an initial rhythm of pulseless ventricular tachycardia or ventricular fibrillation, both shockable rhythms, have significantly better odds of survival compared to those with nonshockable rhythms (e.g., asystole). Among EMS-treated patients with OHCA in 2015, 21.3% presented with an initial shockable rhythm [2]. Rapid access to defibrillation, therefore, is paramount to OHCAvictim survival with optimal neurological and functional outcomes [7]. Although the likelihood of survival is increased when by- standers witness, recognize, and respond to OHCA victims in a rapid manner, barriers to this full potential persist [8].

Over the past decade, cardiac resuscitation systems of care have been developed to increase bystander access to defibrillators [7]. In Denmark, Hansen and colleagues (2017) examined the association between AED placement and both by- stander defibrillator and survival rates after nationwide dissemination of AEDs, registration of AEDs with location linked to EMS dispatchers, dispatcher-guided use, and public education [9]. Bystander defibrillation rates increased in public areas, whereas residential areas remained unchanged. Public locations were significantly associated with a higher proportion of shockable rhythms; increased rates of bystander CPR in progress by the time 911 calls were received; sustained return of spontaneous circulation; and patient survival to hospital discharge compared to residential locations [9]. These findings emphasize the importance of rapid access to AEDs, strategic placement of AEDs in public locations, and that nationwide efforts to facilitate bystander defibrillation have been successful. However, most communities do not achieve rapid survival despite wide dissemination of public access AEDs [9]. OHCA victims in rural and mountainous areas remain disadvantaged in emergency cardiac care [10–12]. Barriers to public access defibrillation (PAD) include but are not limited to: knowledge and awareness; acquisition and maintenance; willingness to use; availability and accessibility; training issues; and registration and regulation [13]. PAD is both difficult to implement and impractical because of the rarity of cardiac arrest in the larger community. One of the primary barriers to PAD is the strategic placement in largely public locations for bystanders to find, retrieve, and bring to OHCA victims [7, 14]. Public locations, such as shopping malls, are limited by hours of operation and only 20% of OHCAs occur in public settings.

A new and promising strategy for increasing rapid access to defibrillation is through unmanned aerial vehicles (UAV), or drones, equipped with defibrillators [15]. UAVs are defined as aircraft vehicles that can be flown autonomously without the need of a pilot on board. Drones equipped with AEDs (AED drones) can augment EMS to potentially increase both public and private access to defibrillators for OHCA victims. In this approach, when a bystander activates an emergency response system (911 in the U.S), the dispatcher could deploy AED- equipped drones in conjunction with EMS for suspected OHCA events. If the drone arrived before EMS, the bystander would then have the opportunity to apply the AED to the victim with the possibility of assistance from the emergency response dispatcher [16•]. This strategy could be particularly useful for accessing "hard to reach places" such as rural settings and mountainous areas, where EMS has long transport times (Fig. 1) [10]. While promising, there are substantial unknowns regarding technical, clinical, and ethical issues. The purpose of this review is to examine the use of drones in medicine, what is currently known, and clinical implications for advancing emergency cardiac care.

Drones in Medicine

The application of drones in medicine is a novel and emerging concept. Drones were first introduced for various military operations in the late 1900s/early 2000s [17]. Today, they are a rapidly advancing technology with increasing worldwide applications, including adoption into the healthcare industry, which can benefit from their array of technical capabilities [18]. Healthcare applications include, but are not limited to: provision disaster assessments, delivering aid packages, medicine, vaccines, blood, and other medical supplies to remote areas; transport of disease test samples and test kits, mobility assistance to elderly populations with robot-like technology, and potential for providing rapid access to automated external defibrillators for patients in cardiac arrest [18, 19]. Other applications include public health surveillance tools, search and rescue, small package delivery to communities affected by major disasters, and communication hotspots for surgeons operating in rural areas [20•]. Future applications in medicine may include the use of diagnostic capabilities, likely in the imaging field. Research supporting these efforts is new yet rapidly growing.

Drones in Emergency Cardiac Care

Innovations in drone technology are emerging in emergency cardiac care. Research about AED-equipped drones is new and has primarily focused on time elements because rapid intervention is critical for patient outcomes [21•]. Drones may be safe and feasible for delivering an AED for out-of-hospital cardiac arrest using Geographic Information System (GIS) tools, which could automatically deploy drones [20•]. Research into AED drones are timely because of recent attention towards the prehospital period (i.e., symptom onset to emergency department arrival) to reduce total ischemia burden time (i.e., symptom onset to reperfusion) [22]. In 2016, Pulver et al. developed a geographical approach for distribution of an AED-equipped drone network, designed to minimize travel time to reach OHCA victims [23•]. Investigators used census block groups for demographic data and cardiac incidence rates to develop three potential drone network configurations to cover a geographically diverse region of 2080 km2. Investigators used GIS to compare travel times between current EMS data (from existing EMS infrastructure) and determined optimal spatial configurations of a medical drone network [23•]. Investigators found that a network of drones could cover 90% of cardiac arrest demand within a minute, as compared to the current response coverage of 4.3% with current EMS organization [23•]. In 2017, Sweden investigators conducted a study to compare times between drone delivery and EMS delivery to OHCA sites, where consecutive OHCAs occurred prior [16•]. Investigators compared the time for drone delivery with time to EMS arrival, the later which was identified through an ongoing Swedish Registry for Cardiopulmonary Resuscitation. They developed a drone equipped with a global positioning system (GPS), highdefinition camera, and an integrated autopilot software system [16•]. Investigators stored the drone at a fire station in a community selected for restricted airspace, extensive delay in EMS response times, and a heavy population in the summer that could benefit from a drone system. The drone was dispatched for out of line of sight locations where prior OHCAs had occurred and drone arrival time to OHCAs sites was significantly less compared to EMS arrival times (5.21 min vs. 22 min, $p < 0.001$) [16•]. Investigators concluded that autonomous transport and delivery of AED with drones were practical and feasible. Drones also delivered AEDs faster than EMS in rural regions, which has great potential for improving access to care and decreasing disparities for victims in rural areas [10]. OHCA victims in remote areas suffer worse outcomes than those in densely populated regions because EMS often cannot quickly reach them. Finally, investigators reported no adverse events nor technical issues during any of the out-of-sight flights. Most recently, another group used geographical and mathematical models to design a drone network in a large area composed of rural and urban regions [21•]. Investigators used a theoretical drone network to quantify the drone network size required to deliver an AED faster than the median 911 times reported for the region. They found that a drone network reduced the median AED arrival time by 3 min compared to the historical 911 response and reduced the 90 percentile of AED arrival time by 10 min and 34 s in the most rural region and by 6 min and 43 s in the most urban region [21•].

Our team recently designed a drone deployment network for North Carolina using mathematical optimization models to select drone station locations among existing infrastructure (in press). We specified the number of drone stations and targeted AED arrival time and compared patient outcomes and expected costs over the drone's lifespan (4 years). Our study determined that drone-delivered AEDs organized in a statewide drone deployment network could improve survival and neurological outcomes at a reasonable expense. Furthermore, strategizing docking stations within a 5-min delivery goal was feasible and cost-effective. We demonstrated that wellestablished mathematical coverage models could be an effective tool to select docking station locations that reduce time to defibrillation.

Human and Technology Interaction: Bystander and EMS Personnel

Despite rapid developments in emergency cardiac care, there is a lack of research regarding bystanders' responses to AED drones and about training required for drone technology. We also need to examine the interplay between human and drone interaction, especially in the context of OHCA. Prior work demonstrates that bystanders' willingness to use PADs is an ongoing barrier [13]. Prior work about bystander CPR may inform bystanders' readiness to interact with an AED drone. A prior study determined bystander CPR rates and patient survival increased when laypersons received CPR training, dispatch-assisted CPR or telecommunicator CPR (T-CPR) [24]. To increase rates of bystander CPR, prior studies have primarily focused on (1) educating bystanders in CPR, and (2) telephone cardiopulmonary resuscitation (communicator CPR) [24]. This highlights the important role of EMS telecommunicators because they potentially can facilitate the early identification of suspected OHCAs and provide CPR and AED coaching to callers [25]. Barriers exist to optimal telecommunicator CPR and include: the caller not being with the victim, language barrier, leaving the phone, refusing CPR instructions, experiencing emotional distress, or difficulty accessing the patient, and placing them on a flat service for CPR [25]. This may inform future directions about needs for bystander training and education. In addition, more research is needed to examine the complex domains between human and drone interplay as part of different strategies to enhance by- stander CPR rates and improve OHCA outcomes [24]. We require understanding of how EMS personnel would interact with bystanders and drones. EMS telecommunicators would play a significant role in integration of drones for OHCA, and many of their current responsibilities would carry over to callers seeking instruction for AED use. Future research needs to examine barriers to successful implementation, integration, and acceptability of drones among emergency cardiac care personnel and laypersons.

Rules and Regulation

Drones are quickly emerging across the United States, and the surge presents regulation challenges. The Federal Aviation Administration (FAA) currently maintains strict drone guidelines that include drones always be in the line of sight of a pilot [26]. Drone usage is limited or restricted in certain geographical areas; nor can drones exceed an altitude of 400 feed or go faster than 100 miles per hour. The FAA is beginning to establish formal regulations for commercial drones carrying medical supplies beyond experiments and research studies [20•]. The Department of Transportation and NASA are working with drone manufacturers and service companies to establish a balance between safety, awareness, and innovation while exploring ways to safely integrate drones into high population environments and high-density traffic airspaces. North Carolina is a test case location under the FAA UAV Integration Pilot Program that started in June 2018 to evaluate the local implications for medical supply delivery with drones over a 3-year period.

Future Directions

Future studies are needed to determine how well AED- equipped drones perform under varying conditions such as weather or time of day. Before a network of drones for medical use can be reliably implemented, we need a strong understanding about technical issues related to battery life, payload capacity, and the ability to detect and avoid problems especially out of line of site. Future research is needed about safety issues such as drones' ability to avoid near misses, collisions, accidents, hijacking, how they could guard against intentional threats to public safety, and by- stander interactions. We need to examine administrative issues including drone certification, operator training and licensing, and the service provider's legal compliance, fiscal health and compliance, and service costs.

Decisions regarding strategic placement of drone deployment locations is challenging to both public and private sectors. Location models based on mathematical concepts have been used prior to inform emergency service provisions; yet, further research is needed to understand how medical drone placement locations may vary by factors such as geography and weather. Future research is needed to better understand challenges associated with implementation of autonomous networks and to examine cost-effectiveness.

Conclusion

Patients suffering OHCA require rapid defibrillation for survival and optimal neurological outcomes. AED equipped drones have the potential to reduce barriers and increase rapid access for OHCAvictims, especially in rural areas. Drones are an innovative and potentially powerful mechanism to increase bystander access to life-saving interventions and patient outcomes. Early research demonstrates drones are feasible in this context, yet future work needs to explore human-drone interactions. AED-equipped drones are promising for improving patient survival, outcomes, and quality of life.

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Compliance with Ethical Standards

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Fig. 1.

Drones equipped with AED shave potential to improve access to life-saving care in rural communities (photo taken on August 2, 2018 by JZH)