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Time to delivery of an automated external defibrillator (AED) using a drone to improve out-of-hospital cardiac arrest (OHCA) mortality

Vivian Nguyen
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Abstract
Background: According to the American Heart Association (AHA), 2018 incidence of out-of-hospital cardiac events (OHCA) that is assessed by emergency medical services (EMS) is 140.7 people per 100,000 population. The time it takes for AED arrival on scene is heavily impacted by AED accessibility and EMS coverage, especially in rural areas. Traditionally, patients who require defibrillation only have 2 methods of obtaining a shock, which are via a bystander or provided by EMS, both of which take time to obtain. Theoretically, if drones can deliver AEDs faster than traditional EMS response times to provide more timely shocks, then OHCA mortality could decrease significantly.

Methods: An exhaustive literature search using the following engine searches was conducted: MEDLINE-PubMed, TRIP-Turning Research Into Practice, Web Science, and CINAHL using the search terms drones, AED(s), and defibrillator(s). These searches were screened using eligibility criteria and were critically appraised and assessed for quality using GRADE guidelines.

Results: A systematic review was conducted and 3 observational studies were ultimately included. One study found using pre-existing EMS infrastructure in addition to establishment of new drone launch sites was the most efficient method, which provided 90.3% coverage within the 1-minute time frame. Another study assessed a region-specific network, which revealed that AED-equipped drones arrived before emergency responders in 94.6% of cases for the 3-minute response reduction goal. The other study found that drones in rural locations were predicted to arrive with an AED before EMS responders in 93% of OHCA cases, which saved an average of 19 minutes travel time.

Conclusion: Given the current evidence and future research to be done, integrating a drone network to deliver AEDs to increase accessibility to the public in different settings is a feasible addition to existing EMS infrastructure to help save lives. However, public acceptance and policy change would be required to implement a medical drone network to deliver AEDs. Future studies need to be conducted that control for many confounding factors in order to properly assess the efficacy of drone-delivered AEDs to OHCA mortality rate specifically.

Keywords: Drones, AED(s), defibrillator(s)

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Degree Name
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Keywords
drones, AED(s), defibrillator(s)

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Time to delivery of an automated external defibrillator (AED) using a drone to improve out-of-hospital cardiac arrest (OHCA) mortality

Vivian Nguyen

A Clinical Graduate Project Submitted to the Faculty of the School of Physician Assistant Studies

Pacific University
Hillsboro, OR

For the Masters of Science Degree, August 9, 2019

Faculty Advisor: Brent Norris, PA-C

Clinical Graduate Project Coordinator: Annjanette Sommers, PA-C, MS
Biography

Vivian Nguyen was born and raised in Albuquerque, NM. She received her Bachelor of Science degree from the University of New Mexico in 2017 with a major in Exercise Science and minor in Chemistry. Her clinical background includes being a medical scribe in the emergency room as well as volunteering with hospice patients and teens with autism. She is interested in pursuing her PA career in emergency medicine and international medical services.

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I would like to thank all of those that have supported me and stuck by my side through this incredibly arduous journey towards becoming a PA even when I was not the easiest person to love. This is for you, mom and dad.
Abstract

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**Results:** A systematic review was conducted and 3 observational studies were ultimately included. One study found using pre-existing EMS infrastructure in addition to establishment of new drone launch sites was the most efficient method, which provided 90.3% coverage within the 1-minute time frame. Another study assessed a region-specific network, which revealed that AED-equipped drones arrived before emergency responders in 94.6% of cases for the 3-minute response reduction goal. The other study found that drones in rural locations were predicted to arrive with an AED before EMS responders in 93% of OHCA cases, which saved an average of 19 minutes travel time.

**Conclusion:** Given the current evidence and future research to be done, integrating a drone network to deliver AEDs to increase accessibility to the public in different settings is a feasible addition to existing EMS infrastructure to help save lives. However, public acceptance and policy change would be required to implement a medical drone network to deliver AEDs. Future studies need to be conducted that control for many confounding factors in order to properly assess the efficacy of drone-delivered AEDs to OHCA mortality rate specifically.

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List of Abbreviations

AED    automatic external defibrillator
AHA    American Heart Association
EMS    emergency medical services
GIS    geographic information system
GRADE  grading of recommendations, assessments, developments, and evaluations
MCE    multi-criteria evaluation
OHCA   out-of-hospital cardiac arrests
ROSC   return of spontaneous circulation
UAV    unmanned aerial vehicles
Time of delivery of an automated external defibrillator (AED) using a drone to reduce out-of-hospital cardiac arrest (OHCA) mortality

BACKGROUND

According to the American Heart Association (AHA),\(^1\) the 2018 statistics regarding incidence of out-of-hospital cardiac events (OHCA) assessed by emergency medical services (EMS) is 140.7 people per 100,000 population. These numbers do not account for OHCA events that are not assessed by EMS, so it is likely that the statistics are underrepresenting the realistic number of OHCA nationwide. Moreover, between 180,000 and 400,000 deaths caused by cardiovascular disease overall are sudden, unpredictable cardiac deaths. This elicited further research that confirmed automatic external defibrillators (AEDs) significantly improve survival after cardiac arrest episodes.\(^2\) For over 50 years, research has shown return of spontaneous circulation (ROSC) is not likely achieved via a defibrillator if the shock was delivered more than 3 minutes after ventricular fibrillation onset.\(^3\) However, many organizations including the AHA have adopted the 8-minute standard, which is the target time from the dispatcher receiving the emergency call to arrival of a defibrillator on scene.\(^4\) De Maio and colleagues\(^4\) tested this 8-minute standard and their results revealed that a reduction of 1 minute (7 minutes to defibrillation) can save an additional 23 lives per year and a reduction of 2 minutes (6 minutes to defibrillation) would save up to 51 more lives per year caused by OHCA. So why settle for this 8-minute goal?

Traditionally, patients who require emergency defibrillation only have 2 methods of obtaining a shock via AED: 1) a bystander who finds and accesses a static AED in public locations or 2) provided by EMS who arrive on scene.\(^5\) Therefore, time
required for AED arrival is heavily impacted by AED accessibility and EMS coverage, especially in rural areas compared to urban areas. Hansen et al\textsuperscript{6} explored AED accessibility and its effects on AED coverage over 17 years of data. They found 61.8% of all cardiac arrests occurred in public locations. Subsequently, AED coverage in public locations decreased significantly by 53.4% outside of normal business days (ie, evening, nighttime, and weekends),\textsuperscript{6} which may have been due to lack of access to the nearby AED (ie, building closures, lack of badge access). Rural areas have even more difficulty accessing timely life-saving treatment due to delay in EMS arrival times in conjunction with daytime public AED accessibility.

Historically, drones or unmanned aerial vehicles (UAV) are already being used worldwide and were deployed for the first time unrelated to military use after major natural disasters, including the Haiti earthquake in 2010, hurricane Sandy in 2012, and the Nepal earthquake in 2015.\textsuperscript{7} The drones delivered small aid packages and had abilities to fly over terrain that was unsafe for ground travel. Previous studies\textsuperscript{7} have already proven that drones are a safe and feasible alternative for providing other medical services, including delivery of blood products, vaccines, and testing kits, especially to communities with poor road systems, disease endemic areas, or have limited healthcare provider availability. Theoretically, if drones can deliver AEDs faster than traditional EMS response times to provide timely shocks, then OHCA mortality could decrease significantly. Are drones the future’s answer to saving lives?

METHODS

An exhaustive literature search using the following engine searches was conducted: MEDLINE-PubMed, TRIP-Turning Research Into Practice, Web Science, and
CINAHL. The following search terms were used: drones AND (AED OR AEDs) AND (defibrillator OR defibrillators). References from relevant articles were searched and inclusion criteria were applied for screening. Included studies were those that conducted primary research evaluating arrival of an AED that is delivered via drone in comparison to standard EMS times and subsequently, measuring potential reduction in mortality due to OHCA. Other inclusion criteria required that studies were published in the English language. Studies were excluded if the study was not primary research, used repeat data sets from other studies and were research letters, editorials, or commentary or concept papers. The quality of relevant articles was evaluated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Working Group guidelines.

RESULTS

The initial search through the 4 aforementioned databases yielded 41 records in total. After screening for relevancy to the clinical question, removing any duplicate records, and excluding articles using exclusion criteria, 3 studies were included in the qualitative synthesis (see Figure 1). All 3 articles were observational studies (see Table 1).

Pulver et al

Conducted in 2016, this study was an observational study that used a mathematical model to calculate theoretical travel times of an AED via drone. Their primary goal was to ensure that one drone was on scene of a cardiac arrest within 1 minute for 90% of all OHCA calls to deliver shock therapy. Their secondary goal was to evaluate implementation costs of this model. The study area was Salt Lake County,
Salt Lake City, Utah, which has a large variety of landscape that is inaccessible by ground transportation including mountains, bodies of water, salt flats, and canyons. The data sets used to create the appropriate mathematical equations were the 2010 Census data combined with OHCA occurring between 2002-2003 in New York City reported by Galea et al, which was used due to availability and the relative match of racial demographics between Salt Lake County and New York City. They used the geographic information system (GIS) to analyze spatial data of established EMS infrastructure. Furthermore, this study used an established location model to determine best placement of AED-equipped drones corresponding to number of OHCA.  

The study observed 3 scenarios: 1) using only preexisting EMS infrastructure for drone launch sites, 2) using only new locations for drone launch sites, and 3) using both preexisting and new locations for drone launch sites. Pulver and colleagues found that the current EMS infrastructure could provide 1-minute response times to only 4.3% overall cardiac arrest demand. When tested, the 3 scenarios provided 80.1%, 90.3%, and 90.3% coverage within the 1-minute time frame, respectively. Overall, the 3rd scenario was the most cost-effective and efficient resolution to increasing AED response times and coverage.

The authors addressed limitations of their study and recognized that their estimations may not be accurate given the data set used was from a different study area. They acknowledged that they did not include other facilities that have similar EMS capabilities, such as hospitals or police stations in their scenario analysis when using preexisting sites as potential drone launch sites, which would have likely
reduced estimated cost and increased overall coverage. Despite the limitations, the authors concluded that this preliminary study shows drone networks show promise to increase survival for victims of cardiac arrest.\(^9\)

**Boutilier et al**

Boutilier and associates\(^10\) conducted this most recent observational study in 2017 to determine whether a drone network could decrease time of AED arrival to an OHCA. Their primary goal was to analyze the required drone network size required to decrease AED response times by 1, 2, and 3 minutes compared to historical EMS response times in different region. Their secondary goal assessed all regions as a large, integrated network to determine if requirement of drone resources would decrease. The study area was greater Southern Ontario, Canada. Data used originated from the Toronto Regional RescuNET that included 8 different regions. Each regions was covered by a different paramedic service for the most part, but nearby paramedic services could respond to a region outside of their own if they were closer to the emergency call. All OHCA calls between January 1, 2006 and December 31, 2014 were included. Excluded calls were those that could not be accurately located due to lack of information. This virtual study used a mathematical model that had two stages: 1) optimization model which determined how many drone bases were needed and the location of those bases to decreases response times and 2) queuing model that determined how many drones each base needed to ensure a drone was available when an OHCA call occurs. The study computed calculations specific to each base taking into account average OHCA events and the average time needed between departures for a single drone, called “drone busy time.”\(^10\)
The region-specific network showed a 63.1% reduction in the 3-minute response time in the most urban region of Toronto, which was equivalent to a reduction of 6 minutes and 43 seconds. Time was reduced by 10 minutes and 34 seconds which corresponds to a 54% time reduction in the most rural town of Muskoka. AED-equipped drones arrived before emergency responders in 94.6% of cases for the 3-minute response reduction goal on average (see Figure 2). The integrated network revealed similar results except response time reduction was not significant for the Muskoka and Halton regions. Regarding the secondary analysis, the region-specific network required more drone resources than the integrated network for all time reduction goals (1, 2, and 3 minutes). However, this resource reduction resulted in decreased drone coverage in Muskoka, the most rural region, since Toronto was the most OHCA-concentrated region.10

The authors theorize that AEDs delivered via drone to achieve defibrillation of a shockable rhythm earlier have the potential to increase survival rates for OHCA patients. They recognize their drone network size is likely overestimated due to their use of both treated and untreated cardiac arrest calls. They also addressed missing response time data for 7.8% of their cases, which may have affected results. However, they conclude that using a strategic approach to placement and number of drones may reduce time to defibrillation on scene and can also be cost-effective, but further research is required to evaluate whether the benefits outweigh the risks of AED drone networks.10

Claesson et al
Claesson et al\textsuperscript{11} conducted an explorative study in 2016 to determine if a drone system can decrease AED delivery time to site of OCHAs, which was their primary aim. Their secondary aim was to investigate whether a drone system to deliver AEDs will be safe, feasible, and efficacious. The study area was Stockholm County, Sweden using retrospective data of OHCAs in Stockholm County between 2006 and 2013. Data analysis had 2 subsections: 1) to conduct a spatial analysis of the best suitable placement of drone bases using a GIS system and 2) to test actual delivery of drones on those sites. For the spatial analysis, they used a tool called the multi-criteria evaluation (MCE) that creates calculations based on the importance of two different factors, which were EMS delay time and OHCA incidence. To appropriately place these bases, rural locations had EMS delay to OHCA incidence weighted 80 to 20, which insinuated EMS delay was a more important factor than OHCA incidence. In comparison, the urban locations had a 50 to 50 weight, which equally weighed EMS delay and OHCA incidence in importance. Both the urban and rural locations each had 10 drone bases.\textsuperscript{11}

This is the only study that conducted test flights of physical drones; however, it was limited due to laws governing civilian use of UAV. Civilians operating drones must fly within the pilot’s range of sight, so the authors tested flights in rural areas and used historical data to calculate travel time based off of these test flights. Furthermore, this is the only study that evaluated the safest deployment of the AED from the drone to bystanders. They tested 3 modes of delivery: 1) drop the AED via parachute from at least 25 meters (75 feet), 2) drop the AED via a latch system that holds the AED in place from 3-4 meters (9-12 feet) in the air, and 3) land the drone on
scene directly. Visual data was collected in conjunction with meteorological data to assess drone performance. The AED was placed on a mannequin model after delivery and evaluation of AED functionality was assessed after attachment.\textsuperscript{11}

Cleasson’s study compared their results to historical data that showed the median response time of AED arrival starting from the time of patient collapse to defibrillation was 11 minutes. Moreover, 30-day survival increased from 31\% to 70\% when a public AED was used before EMS response versus EMS response alone. The AED-equipped drone was predicted to arrive earlier than EMS 32\% of the time, which saved an average of 1.5 minutes of time to delivery in urban areas. In contrast, drones in rural locations were predicted to arrive with an AED before EMS responders in 93\% of OHCA cases, which saved an average of 19 minute in travel time. They found the best and safest techniques for AED deployment from the drone was the latch method from 3-4 meters and landing the drone on a flat surface.\textsuperscript{11}

The authors address limitations of their test flights, stating they are simulations and cannot directly compare to real-time EMS responses, which are affected by call to dispatch time, drone takeoff time, and drone landing time. They acknowledge that rural area drone sites relied on off-season travel times, but those areas are heavily occupied in the summertime, which would change the amount of AED demand. However, the authors can conclude that using a drone network is safe and feasible, especially for rural areas to reduce time of AED arrival, and therefore, provide timely defibrillation to out-of-hospital cardiac arrests.\textsuperscript{11}

\textbf{DISCUSSION}

\textbf{Clinical Relevance}
Through interpretation of results from these 3 observational studies,\textsuperscript{9-11} the authors all theoretically conclude that a drone network equipped with AEDs has great potential to decrease AED arrival time to an OHCA. Therefore, this novel network has great potential to decrease mortality rate attributed to cardiac arrest according to established research. This preliminary research shows that drones can help save cardiac arrest patients in not only rural settings, but also in high building locations or other setting without easy AED access. Drones can provide 24/7 AED availability to both public and private locations and give life-saving support to the bystander through video-assisted technology built into the drone itself. Drones can be equipped with cameras with live streaming capabilities, which the dispatcher can use to help guide the bystander through pre-hospital care including high-quality CPR before EMS arrival.\textsuperscript{13} The dispatcher can also assess situational safety for both the patient and bystander concurrently. However, AED-equipped drones would add another link that must be worked into the chain of survival.\textsuperscript{11}

Furthermore, the likelihood of a layperson to use an AED is another challenge to face. Though AEDs provide clear instructions, many people are either unfamiliar with an AED and its functions or are uncomfortable utilizing it when needed. However, delivery of AEDs directly to bystanders gives them a chance at administering a shock to a cardiac arrest patient as opposed to not having AED access at all. Van de Voorde\textsuperscript{14} argues that a bystander may be more likely to use an AED the closer it is to the patient. Integrating a drone network into society’s daily life may increase comfort and familiarity with AEDs, and bystander use of AEDs may decrease witnessed OHCA
mortality. Public acceptance and policy change is required to implement a medical drone network to deliver AEDs.\textsuperscript{14}

**Limitations**

Each study was critically appraised for quality of evidence and all were deemed very low quality at this time (see Table 1). All studies were inherently “low” quality due to being observational studies that conducted “virtual” data through mathematical models, which was sufficient criteria to downgrade the quality of evidence to “very low”.\textsuperscript{9-11} Furthermore, all 3 studies\textsuperscript{9-11} used time of AED delivery as a surrogate outcome to predict OHCA mortality since they could not assess mortality rate via virtual calculations. An important factor to consider for appraisal was the historical EMS data from which the mathematical calculations were generated. Pulver et al\textsuperscript{9} used a historical data set that encompassed 1 year of EMS times from New York City, New York although the study area was Salt Lake County, Utah.

Drone specifications were vital to consider when assessing studies. Two studies\textsuperscript{9,11} did not explicitly state the type of drone used for calculations nor did they state the specific capabilities of that drone model, which would significantly affect the speed, distance, altitude, and ability to carry an AED. More importantly, knowing the drone’s capabilities determined where drone flight sites were located and how many drones were required at each location. Boutilier et al\textsuperscript{10} was the only study that accounted for drone busy time, which likely plays a large part in determining drone placement. Because all the studies were observational using mathematical models, they did not take account for possible adverse weather conditions, operational error,
or technical malfunctions of the machine except for Claesson et al\textsuperscript{11} who checked functionality of the AED after it was attached to the mannequin.

**Future Research**

With the current very low quality evidence at this time, further clinical studies including randomized trials that have primary endpoints focusing on OHCA mortality rates need to be conducted to validate whether drones can indeed decrease mortality rate caused by cardiac arrest. Studies that control for the many confounding factors mentioned previously should be performed to properly assess the efficacy of drone-delivered AEDs to OHCAs. Moreover, agencies such as the Federal Aviation Administration (FAA) would require guideline changes specifically addressing medical drones and flight restrictions. Security of patient information in compliance with HIPAA would be carefully considered as well as production and maintenance costs in addition to existing EMS infrastructure.\textsuperscript{13}

**CONCLUSION**

Delivery of an AED via drone may be a safe and feasible alternative to provide out-of-hospital emergency services to decrease mortality related to witnessed cardiac arrests. Drones have been used historically to provide other medical services including delivery of medical supplies and/or increase access to healthcare in settings that are otherwise underserved or have physical barriers to accessibility. Future controlled clinical trials need to take place to directly assess mortality rates as effected by use of drone delivered AEDs. Given the current evidence, integrating a drone network to deliver AEDs to increase accessibility to the public in all different settings is a feasible addition to existing EMS infrastructure to help save lives.
REFERENCES


# Tables

## Table 1: Quality Assessment of Reviewed Articles

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Limitations</th>
<th>Indirectness</th>
<th>Inconsistency</th>
<th>Imprecision</th>
<th>Publication bias</th>
<th>Upgrade Criteria</th>
<th>Quality</th>
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</thead>
<tbody>
<tr>
<td>Pulver et al</td>
<td>Observational</td>
<td>Serious&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Not Serious&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Not Serious</td>
<td>Serious&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Unlikely</td>
<td>None</td>
<td>Very Low</td>
</tr>
<tr>
<td>Boutilier et al</td>
<td>Observational</td>
<td>Serious&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Not Serious&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
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<td>Claesson et al</td>
<td>Observational</td>
<td>Serious&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Not Serious&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Very Low</td>
</tr>
</tbody>
</table>

<sup>a</sup> All studies did not measure and assess for all confounding factors, were all “virtual” studies  
<sup>b</sup> All studies use time as a surrogate outcome to predict OHCA mortality  
<sup>c</sup> Data set only encompassed 1 year of data that was used to locate areas of drone placement
FIGURES

Figure 1. Record of search, adapted from Prisma 2009 Flow Diagram\textsuperscript{12}

- Records identified through database searching \((n = 41)\)
- Additional records identified through other sources \((n = 0)\)
- Records after duplicates removed \((n = 24)\)
- Records screened \((n = 18)\)
- Articles not meeting inclusion criteria \((n = 10)\)
- Full-text articles assessed for eligibility \((n = 8)\)
- Full-text articles excluded, with reasons \((n = 5)\):
  - 1 not in English language
  - 4 repeat data set from previous study
- Studies included in qualitative synthesis \((n = 3)\)

Figure 2. Comparison of response times distributions (Boutilier et al\textsuperscript{10})