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CLINICAL RESEARCH
Clinical trials

Automated external defibrillators delivered by drones to patients with suspected out-of-hospital cardiac arrest

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Aims
Early defibrillation is critical for the chance of survival in out-of-hospital cardiac arrest (OHCA). Drones, used to deliver automated external defibrillators (AEDs), may shorten time to defibrillation, but this has never been evaluated in real-life emergencies. The aim of this study was to investigate the feasibility of AED delivery by drones in real-life cases of OHCA.

Methods and results
In this prospective clinical trial, three AED-equipped drones were placed within controlled airspace in Sweden, covering approximately 80 000 inhabitants (125 km^2). Drones were integrated in the emergency medical services for automated deployment in beyond-visual-line-of-sight flights: (i) test flights from 1 June to 30 September 2020 and (ii) consecutive real-life suspected OHCAs. Primary outcome was the proportion of successful AED deliveries when drones were dispatched in cases of suspected OHCA. Among secondary outcomes was the proportion of cases where AED drones arrived prior to ambulance and time benefit vs. ambulance. Totally, 14 cases were eligible for dispatch during the study period in which AED drones took off in 12 alerts to suspected OHCA, with a median distance to location of 3.1 km [interquartile range (IQR) 2.8–3.4). AED delivery was feasible within 9 m (IQR 7.5–10.5) from the location and successful in 11 alerts (92%). AED drones arrived prior to ambulances in 64%, with a median time benefit of 01:52 min (IQR 01:35–04:54) when drone arrived first. In an additional 61 test flights, the AED delivery success rate was 90% (55/61).

Conclusion
In this pilot study, we have shown that AEDs can be carried by drones to real-life cases of OHCA with a successful AED delivery rate of 92%. There was a time benefit as compared to emergency medical services in cases where the drone arrived first. However, further improvements are needed to increase dispatch rate and time benefits.

Trial registration number
ClinicalTrials.gov Identifier: NCT04415398.

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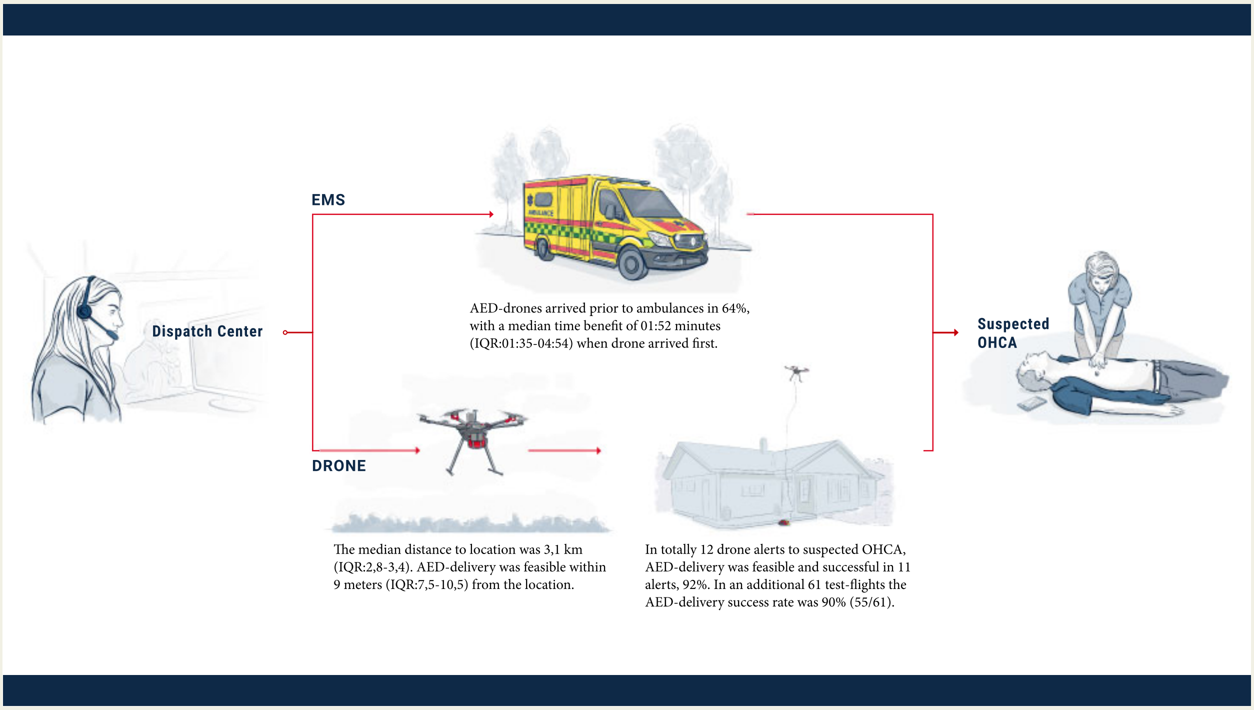
Graphical Abstract



The dispatch centre alerts emergency medical services and a drone equipped with an automated external defibrillator for response to suspected out-of-hospital cardiac arrest. Data are presented with interquartile range for time benefit (min:s) and distance to the location (kilometres to the site and metres to the object when winching down the automated external defibrillator).

Keywords OHCA • AED • UAV • Drone

Background

Efforts to increase survival in out-of-hospital cardiac arrest (OHCA) need to be prioritized because of low survival rates (∼11%).[1–4] Early treatment in line with the 'chain-of-survival' concept such as cardiopulmonary resuscitation (CPR) and defibrillation by an automated external defibrillator (AED) prior to ambulance arrival is associated with increased survival.[5,6] Use of AEDs in the early-cardiac-arrest electrical phase[7] can increase survival rates to up to 50–70%.[8–10] Although hundreds of thousands of AEDs are available in high-income countries, their accessibility and use are still low.[11–14] In Sweden, time to ambulance arrival has increased over the years, reports from 2019 showing that the median time was 11 min.[15] Therefore, new methods of reaching OHCA victims earlier are needed.

Unmanned aerial vehicles (drones) with the ability to carry AEDs represent a promising novel method to deliver AEDs.[16–18] However, this has never been evaluated in a real-life emergency setting. Theoretical studies and simulations have confirmed the theoretical timesaving potential.[19] Furthermore, recent simulations of AED delivery and bystander interaction within the line of sight in rural areas have confirmed the potential of an AED drone system,[20–22] and clinical real-life studies have been warranted for a long time.[21–25] Due to a relatively high incidence of OHCA, geographical areas such as semi-urban areas with relatively long response times show theoretical potential for using a complementing system of AED drones.[26] Our aim was to test, for the first time ever in a real-life setting, the feasibility of drone delivery of AEDs as a complement to standard care in a semi-urban area.

Methods

Trial oversight

This is a prospective clinical feasibility trial conducted between 1 June and 30 September 2020 in three areas within the controlled airspace of Säve Airport, Gothenburg, Sweden, covering 125 km^2, with about 80 000 inhabitants (*Figure 1A*). AED-equipped remotely operated drones were placed in automated hangars (*Figure 2*). Drones were daily available for dispatch between 08:00 and 22:00 h, when the airspace was open. Drones were consecutively dispatched in real-life suspected OHCAs as a complement to standard emergency medical services care (ambulance). In addition to the real-life OHCA flights, test flights were performed regularly during the study period. The study was approved by the Swedish

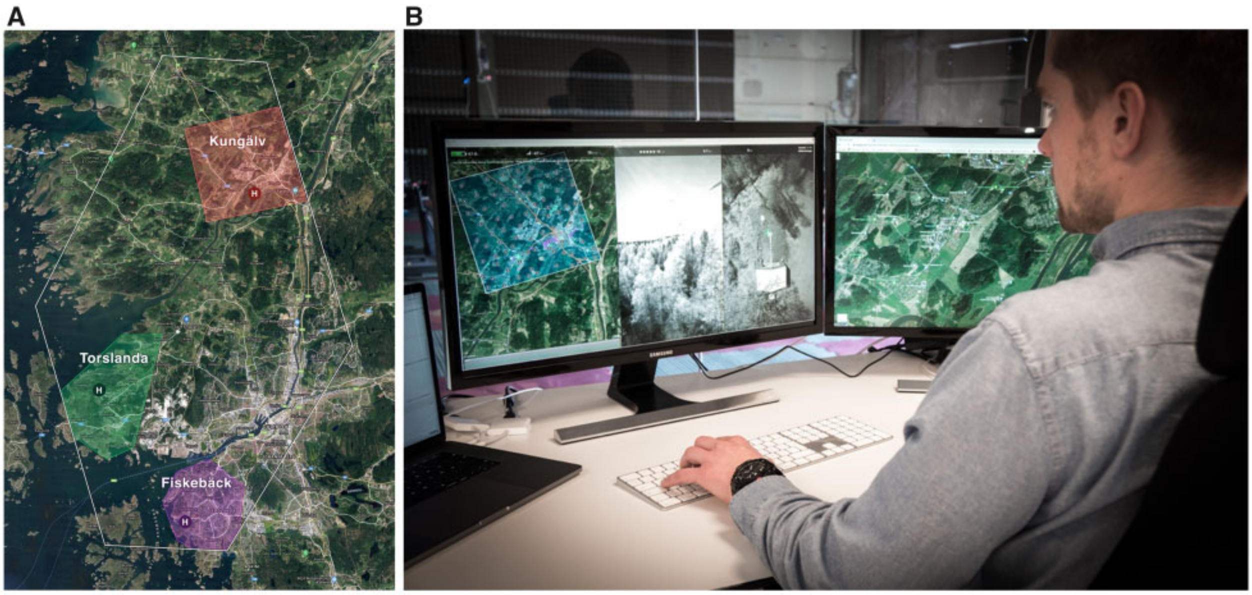


Figure 1 (*A*) Administrative areas within Säve airport controlled airspace, Gothenburg, Sweden. Map overview of automated external defibrillator-equipped drones with hangar placement (H) within three administrative areas: Kungälv 52.2 km^2, Torslanda 42.8 km^2, and Fiskebäck 30 km^2. All situated within the controlled airspace of Säve Airport, Gothenburg, Sweden. Total coverage 125 km^2 with about 80 000 inhabitants. (*B*) Drone mission-control centre with remote pilot. Everdrone Mission-Control Center at Säve airport for remote dispatch of three AED-equipped drones. Control centre manned during the study period of 1 June to 30 September 2020 between 08:00–22:00, i.e. during Säve-controlled airspace operational hours.

ethics review authority (29 January 2020, registration no. 2019-06139, ClinicalTrials.gov Identifier: NCT04415398).

Drones, soft/hardware, and automated external defibrillators

Drones and pilots

Standard DJI Matrice 600 Pro hexacopter drones were modified for AED delivery. They were in automated remotely operated hangars controlled by a drone-operator mission-control centre (*Figure 1B*). The remote pilot training consists of 1-day general training in accordance with the Swedish Transport Agency's category 2 certificate and a 5-day internal study pilot training at Everdrone company. This education and training programme covering 5 days including theoretical and practical exercises in handling operations manual, checklists, UAV knowledge, pilot user interface, and emergency procedures. Each drone weighed 12.5 kg and could execute operational flights in dry conditions and median winds of <8 m/s. Flights were at 65 m altitude and range 5 km from the hangar.

Soft/hardware

The drones were fitted with specially designed hardware and software from Everdrone AB (Sweden) (everdrone.com), including a sense and avoid system, an emergency parachute, and a winch-system for the specific application of delivering AEDs to real-life suspected OHCAs.

Automated external defibrillators

Standard Schiller FRED Easyport AEDs (schiller.ch), total weight 800 g including delivery basket and wire, were used. They were winched down from a prespecified 30 m altitude and placed as close as possible to the scene of the suspected OHCA.

Trial procedures

Run-in phase and study areas

The system was tested prior to the study over a 4-month period (1 February to 31 May 2020). Simulations were carried out with dispatchers, bystanders, and pilots to optimize AED delivery. Three administrative areas were defined and set up in detail within Säve-controlled airspace as regards no-fly-zones, residential areas, military facilities, and high-rise objects (>20 m; five stories).

Drone dispatch system

During the following 4-month study period (1 June to 30 September 2020), when dispatch centres indexed a suspected cardiac arrest during an emergency call, an automated alert was sent to the drone pilot, who immediately initiated pre-flight checks. The hangar automatically opened, flight systems were initiated, and route-planning software calculated the optimal flightpath with a focus on minimizing the proportion (%) of flight-time above populated areas. For each flight, the drone pilot requested permission from air-traffic control by telephone to deploy the drone to a location within the administrative area in airspace up to 500 ft (150 m) above mean sea level. The drone then flew, autonomously and out of sight, to the coordinates of the suspected OHCA, where the pilot manually approved drop point and initiated AED delivery. The drone then returned to the hangar. For data collection and adverse events, see Supplementary material online, *Appendix S1*.

Figure 2 (*A*) Automated external defibrillator drone hangar in administrative area—Kungälv. Drone hangar 8 m × 5 m (width/depth) with continuous surveillance of weather conditions and drone system status, automated port and external markers for autonomous takeoff and landing of automated external defibrillator-equipped drones. (*B*) Automated external defibrillator-equipped drone. DJI Matrice 600 Pro hexacopter drone with Everdrone software and hardware. Drone equipped with emergency parachute system, sensors for safe autonomous flight, winch system, and Schiller FRED Easyport semi-automatic automated external defibrillator. (*C*) Automated external defibrillator-equipped drone with winch used to deliver the automated external defibrillator. Automated external defibrillator-equipped drone in-flight during winch of automated external defibrillator from 30 m altitude. (*D*) Automated external defibrillator delivery onsite during test flight. Automated external defibrillator delivered in padded basket onsite with siren attracting attention. The dispatcher instructs bystanders to retrieve the automated external defibrillator as a part of the telephone-assisted cardiopulmonary resuscitated protocol.

Core outcome variables

The primary outcome measure was the proportion of successful accurate AED deliveries when drones were dispatched and took off in cases of suspected cardiac arrest. This measure was chosen because many factors such as weather conditions and route planning were known in advance to prohibit flights.

The secondary outcome measures were (i) proportion (%) of suspected OHCA with AED drone arrival prior to ambulance; (ii) time difference: drone vs. ambulance arrival; and (iii) proportion of drone-delivered AEDs attached prior to ambulance arrival (%).

Inclusion and exclusion criteria

Inclusion criteria were (i) consecutive dispatcher-suspected OHCA within study/administrative areas and (ii) hours of operation: 08:00–22:00.

Exclusion criteria pre-alert were (i) children <8 years, (ii) trauma, and (iii) emergency medical service (EMS)-witnessed OHCA. Exclusion criteria post-alert were (i) darkness, (ii) rainy conditions, any rain, (iii) wind ≥8 m/s, (iv) high-rise buildings >5 stories (20 m), (v) no-fly zones, and (vi) alerts geographically out of range within administrative area.

Test flights

In addition to the real-life study, beyond-visual-line-of-sight test flights were performed regularly during the study period to train drone pilots and evaluate the feasibility of AED delivery using drones and various heterogeneous objects (see Supplementary material online, *Appendix S2*).

Statistical analysis

Descriptive data were calculated using Excel; proportions (%) are presented at group level. Time delays are given as medians with interquartile ranges (IQR).

Table 1 Outcome of real-life automated external defibrillator deliveries using drones in suspected out-of-hospital cardiac arrest

Variable	AED drone real-life flights	Ambulance	AED drone test flights
Total number of cases	12	12	62
Flights			
Distance to location, km median (IQR)			
- Direct route	2.5 (2.3–2.7)	NA	2.1 (1.2–2.7)
Missing (1, 0, 10)[a]			
- Actual route	3.1 (2.8–3.4)	4.3 (3.2–9.4)	2.7 (1.3–3.4)
Missing (0, 0, 0)[a]			
Distance from AED drop to building/patient, m (IQR)	9 (7.5–10.5)	NA	10 (7–13.8)
Missing: (1, NA, 6)[a]			
AED drop accuracy <3 m (%)	100%	NA	100%
Missing: (1, NA, 6)[a]			
Median in-flight speed, km/h (IQR)	47.3 (46.6–48.9)	NA	45.8 (41.4–48.1)
Missing: (1, NA, 8)[a]			
Flight-distance above populated areas, % (IQR)	11 (8–16)	NA	13 (7–28)
Missing: (1, NA, 30)[a]			
Time delays			
Time from 112 call[b] to indexing of suspected OHCA at EMDC, min:s (IQR)	01:06 (00:41–01:46)		NA
Missing: (0, 0, NA)[a]			
Time from 112-call to dispatch, min:s (IQR)	01:48 (01:19–2:39)	01:41 (01:30–02:47)	NA
Missing: (0, 0, NA)[a]			
Time from dispatch to acknowledgement of alarm, min:s (IQR)	00:04 (00:04–00:04)	00:47 (00:29–01:08)	NA
Missing: (0, 0, NA)[a]			
Time from dispatch to ATC clearance, min:s (IQR)	00:47 (00:42–00:53)	NA	NA
Missing: (0, NA, NA)[a]			
Time from ATC call to ATC clearance, min:s (IQR)	00:22 (00:19–00:26)	NA	00:25 (00:21–00:35)
Missing: (0, NA, 9)[a]			
Time from dispatch to take-off, min:s (IQR)	01:22 (01:19–01:32)	NA	NA
Missing: (1, NA, NA)[a]			
Time from take-off to AED delivery, min:s (IQR) (response time)	05:23 (05:10–06:07)	06:40 (05:36–07:31)	04:50 (03:07–05:53)
Missing: (1, 1, 7)[a]			
Total time from dispatch alert to AED delivery/arrival, min:s (IQR)	06:45 (06:31–07:45)	07:47 (06:57–08:22)	NA
Missing: (1, 1, NA)[a]			
Total time from 112-call to AED delivery/arrival, min:s (IQR)	09:08 (08:30–10:12)	09:53 (08:52–10:22)	NA
Missing: (1, 1, NA)[a]			
Core outcome variables			
Primary endpoint			
Delivery of AED successful, n (%)	11/12 (92)	NA	56/62 (90)
Secondary endpoints			
AEDs attached prior to EMS arrival (%)	0 (0)	NA	NA
Delivery of AEDs prior to EMS (%)	7/11 (64)	NA	NA
Time benefit compared with ambulance when drone first, min:s (IQR) Missing (1)[a]	01:52 (01:35–04:54)	NA	NA

ATC, air traffic control; EMDC, emergency medical dispatch centre; AED, automated external defibrillator; OHCA, out-of-hospital cardiac arrest; EMS, emergency medical service; IQR, interquartile range; NA, not available.
[a]Missing per column.
[b]112 is the emergency number in Sweden.

Table 2 Case-by-case dispatch of automated external defibrillator-equipped drones to real-life suspected out-of-hospital cardiac arrest June–September 2020

Variable	Administrative area	Date	Direct flight distance to location (km) and proportion above populated areas (%)	Actual flight distance to location (km) and proportion above populated areas (%)	Direct route, estimated total flight time from take-off to arrival (min:s)	Actual route, total flight time from take-off to arrival (min:s)	In-flight speed (km/h)	AED drop distance to object (m)	AED drop accuracy distance from drop point (m)	Delivery before EMS
Flight #										
1	Torslanda	3 June	2.65 (43)	3.5 (8)	04:20	06:30	46.3	9	<3	Yes
2	Kungälv	7 June	2.79 (4)	2.8 (2)	04:28	05:27	48.9	9	<3	Yes
3	Torslanda	14 June	2.8 (74)	3.8 (19)	04:36	06:54	46.5	12	<3	Yes
4	Kungälv	2 July	2.0 (41)	2.5 (13)	03:40	05:14	40.0	5	<3	Yes
5	Kungälv	10 July	2.5 (17)	2.6 (8)	04:08	05:05	47.3	9	<3	No
6	Torslanda	16 July	1.8 (72)	3.2 (11)	03:22	05:08	48.8	12	<3	Yes
7	Kungälv	19 July	2.2 (47)	2.9 (11)	03:49	04:59	49.0	8	<3	Yes
8	Kungälv	23 July	2.4 (88)	2.8 (22)	03:55	05:45	48.9	14	<3	No
9	Fiskebäck	3 August	2.4 (100)	3.1 (49)	04:03	05:12	46.7	9	<3	Yes
10	Torslanda	4 August	2.5 (71)	3.1 (12)	04:11	05:23	46.9	7	<3	No
11	Fiskebäck	10 August	3.4 (87)	4.4 (0)	05:19	07:23	49.0	3	<3	No
Median			2.5 (71)	3.1 (11)	4:08 (IQR 3:49–4:28)	5:23 (IQR 5:10–6:07)	47.3 (IQR 46.6–48.9)	9 (IQR 7.5–10.5)	100%	64%

AED, automated external defibrillator; EMS, emergency medical service; IQR, interquartile range.

Results

Altogether, 53 alerts of suspected OHCA occurred during the study period, from which 39 (74%) were outside of service area or excluded due to predefined exclusion criteria. Totally, 14 cases were eligible for dispatch, AED drones took off in 86% (12/14) and the primary outcome of AED delivery was successful in 92% (11/12) of all cases (Supplementary material online, *Appendix S3*). The secondary outcome of the proportion of AED drones arriving prior to ambulances was met in 64% (7/11) of the cases, with a median time benefit of 01:52 min (IQR 01:35–04:54) (*Table 1*).

The median distance from drone hangar to suspected cardiac arrest was 3.1 km (IQR 2.8–3.4). AEDs were delivered 9 m (median, IQR 7.5–10.5) from the victim, with an accuracy of 100% within 3 m of the expected drop point (*Table 2*). No drone-delivered AEDs were attached prior to ambulance arrival. No AEDs were damaged, and no adverse events occurred during the real-life flights.

Drone service available for dispatch

Overall, the system was operationally available for dispatch to real-life OHCA in 101/122 days (83%) in the study period. In one test flight, the emergency parachute deployed. As a precaution, operations were halted until the issue was resolved, resulting in stalled operations during the last 21 days of the study period. Rain was the predominant prohibiting factor for flights (in 14.3% [24/1708] of all planned operational hours; wind for 0.4% [6/1708 hours]).

Alerts eligible for inclusion

Altogether, 39 (74%) cases were not eligible for inclusion for the following reasons: alert after sunset in one case (2%); weather conditions prohibited flights in nine cases (17%), with rain the predominant factor in eight. In one alert, maintenance of the hangar coincided with the alert, thus prohibiting flight. The target location was inaccessible in 16 cases (30%) because of no-fly zones (high-rise buildings) in eight (15%) and overlong flight distances in another eight. In one case (2%), the dispatch centre failed to alert the drone operator and the service was unavailable in 11 cases (21%) due to the service being offline for system updates at the end of the study period.

Adherence to study protocol and overall time delays

The time delay from answering an emergency call to dispatch of drones was 01:48 (IQR 01:19–2:39) vs. 01:41 (IQR 01:30–02:47) for ambulances. No alerts were missed by drone pilots; time delay from dispatch of the unit to acknowledgement was 4 s. No alerts were missed by air-traffic control; time delay from phone call to request air-traffic control clearance to clearance was 00:22 (IQR 00:19–00:26). Total time from dispatch of drone to air-traffic control clearance was 00:47 (00:42–00:53). Total delay from drone dispatch to AED delivery was 06:45 (06:31–07:45) vs. 07:47 (06:57–08:22) for ambulances (arrival at the address). Overall, the median time benefit of all cases was 00:49 (IQR 00:00–01:52), but in cases where AED drones arrived first the median time before ambulances was 01:52 (01:35–04:54) (*Table 1*).

Test flights

In addition to real-life flights, 61 random beyond-visual-line-of-sight test flights were performed during the study period, with an AED delivery success rate of 55/61 (90%) (see Supplementary material online, *Appendices S1 and S2*).

Discussion

This is, to the best of our knowledge, the first prospective, clinical study where AED-equipped drones are fully integrated as a part of the medical system and dispatched in parallel with the ambulance to real-life cases of OHCA. In addition, we present time benefits as compared to ambulance and a full methodology to deploy AED-equipped drones, a 'proof of concept' constituting a possible paradigm shift by adding a new method in treatment of and societal response to OHCAs (*Graphical abstract*).

We believe this study to be of importance by several reasons. First, the incidence of ventricular fibrillation falls rapidly during the first minutes after collapse as does the chance of surviving a cardiac arrest in waiting for treatment with defibrillation, one of the strongest predictors for increased survival.[8,9] The EMS cannot respond to this time challenge, instead we see that response time intervals have increased over the past 10 years, averaging 11 min in Sweden 2019.[15] Although none of the drone-delivered AEDs were attached to a patient in this early pilot study, we present a novel method that in the future could decrease time to defibrillation and thereby potentially increase survival.

Second, this study describes for the first time a full methodology to deploy AED-equipped drones in a real-life setting. We have shown that it is feasible to integrate a complete drone system all the way from the emergency call to the dispatch centre to fly a drone with final AED delivery onsite. This integration of a drone system into the chain of survival with the dispatch centre and EMS is one of the key challenges in adding a novel modality of emergency response.

Third, drones carrying AEDs could be regarded as a pilot aspect of medical treatment with drones. There are several fields within medicine in which drones could be lifesaving. For example, there are ongoing studies with drones in the field of drowning[24] and delivery of blood and organs.[25,26]

Our study was performed in a populated area surrounding Sweden's second largest city. Simulation studies have confirmed the theoretical timesaving potential using a drone for AED delivery[17,22] and recent studies performed in a rural setting[21] and in campus area[22] are promising but we believe neither of these settings are truly representative as regard to OHCAs. Low incidence rates of OHCA,[27] long geographic distances, and lack of controlled airspace might suggest otherwise in these areas. Semi-urban areas, however, have attributes that suggest that AED delivery by drones might be an effective compliment to traditional resources due to a relatively high incidence rate of OHCA and long EMS response times.[28]

Current guidelines from the European Society of Cardiology recommend that public access defibrillation (PAD) may be established in places where OHCA is relatively common, primarily in public settings.[29] AED-equipped drones could be a complement to PAD systems as they could cover large geographical areas and facilitate early defibrillation also in residential settings.

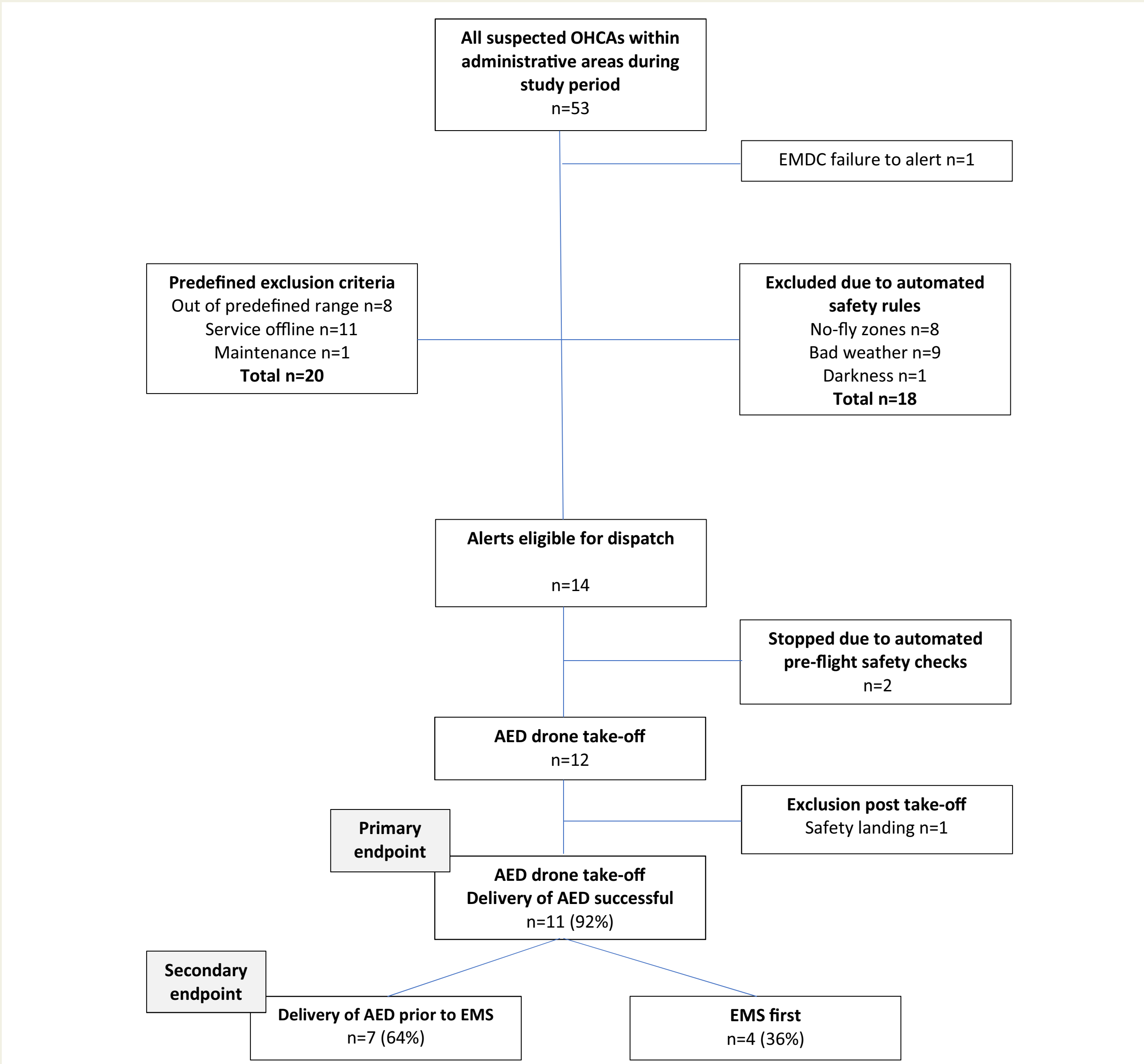


Figure 3 Flow chart of real-life automated external defibrillator drones beyond-visual-line-of-sight flights to suspected out-of-hospital cardiac arrest s. Flowchart of eligible cases during the study period 1 June to 30 September 2020. In a majority of cases, several factors contributed to exclusion, but the predominant cause is presented in the figure. AED, automated external defibrillator; EMDC, emergency medical dispatch centre; EMS, emergency medical service; OHCA, out-of-hospital cardiac arrest.

We identified several future improvements in our system to significantly shorten time to AED delivery and increase the number of eligible alerts. First, our conservative route-planning not to fly above populated areas resulted in a diminished number of eligible alerts as the software calculated distances exceeding the maximum flying distance of the drone. A new and more direct route could contribute to reach both urban and more sparsely populated areas which may result in both higher number of cases reached and a greater time benefit. Second, improved drone performance such as increased speed and better rain- and wind-tolerability could as well lead to more eligible cases as well as optimized hangar placement. Third, another possible way to further enhance early care may be to add AED drone delivery positions to lay responders' smartphone applications for faster use of the AED onsite.[24,26,28,30] This could make it possible to better intervene in OHCA cases, particularly in residential settings, with large populations which up until now have been hard to reach.[14]

There was only one adverse event, which occurred during test flights, which was caused by incorrect activation (false positive) of the parachute. The event did not cause any harm but led to grounding of the drone fleet until the issue was resolved, thus missing out in 11 cases; further enhancement of the parachute system will prohibit incorrect activation (*Figure 3*).

Another important aspect is whether a time benefit of 2 min as compared to EMS is clinically sufficient in terms of survival benefits. Bystanders onsite with guidance from the dispatcher during telecommunicator CPR will need an unknown amount of time to facilitate use of the AED. As none of the drone-delivered AEDs were attached to the patient in this study, more research is needed. In a future optimized system, we expect arrival in ≤7 min and more often in the electrical phase of the cardiac arrest.[7] Data from the Swedish register for CPR[31] show that if time from call for help to defibrillation was reduced <8 min, several additional lives could be saved. The chance to find a patient in a shockable rhythm increases the earlier an AED is connected to the patient. We believe that this kind of AED drone system can add an important tool to this opportunity.

In this study, the median distance from the AED to the patient was 9 m with high drop accuracy; the time it takes to retrieve an AED may therefore be short. A high-rise building, however, is a complication as regards drone delivery of an AED in cases where the caller is alone, disabled, or with the victim at a high level.

For future studies, we suggest implementation of the above-mentioned types of optimizations, more detailed evaluation of the timesaving potential, as well as putting more focus on the clinical effects onsite with bystander activity in relation to AED drone delivery.

In summary, in this early pilot study, AED-equipped drones could be dispatched in parallel with the ambulance to the scene of OHCAs with a substantial time benefit in cases where the drone arrived first and with a successful delivery rate of 92%. Further technological improvements are needed to increase dispatch rate.

Limitations

The study was performed with limited area coverage during a relatively short time-period. Conservative route-planning and drone limitations (speed, not being able to fly in rain, or wind >8 m/s) decreased the number of eligible alerts. The small sample size makes the clinical significance of the time benefit difficult to evaluate. Even though a drone delivered an AED before the arrival of EMS in 64% of the cases, no drone-delivered AED was used in this feasibility study. No analysis of data on AED use and experiences of bystanders onsite are therefore possible. This study was performed during summertime in Sweden and under optimal weather conditions; however, environmental factors may differ between regions and countries, and this must be taken into consideration since it can affect the generalizability of the study.

Conclusion

In this pilot study, we have shown that AEDs can be carried by drones to real-life cases of OHCA with a successful AED delivery rate of 92%. There was a time benefit as compared to EMS in cases where the drone arrived first. However, further improvements are needed to increase dispatch rate and time benefits.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

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Conflict of interest: none declared.

References

1. Perkins GD, Handley AJ, Koster RW, Castrén M, Smyth MA, Olasveengen T, Monsieurs KG, Raffay V, Gräsner JT, Wenzel V, Ristagno G, Soar J; Adult basic life support and automated external defibrillation section Collaborators. European Resuscitation Council Guidelines for Resuscitation 2015: section 2. Adult basic life support and automated external defibrillation. *Resuscitation* 2015;**95**:81–99.
2. Gräsner JT, Lefering R, Koster RW, Masterson S, Böttiger BW, Herlitz J, Wnent J, Tjelmeland IB, Ortiz FR, Maurer H, Baubin M, Mols P, Hadžibegović I, Ioannides M, Škulec R, Wissenberg M, Salo A, Hubert H, Nikolaou NI, Lóczi G, Svavarsdóttir H, Semeraro F, Wright PJ, Clarens C, Pijls R, Cebula G, Correia VG, Cimpoesu D, Raffay V, Trenkler S, Markota A, Strömsöe A, Burkart R, Perkins GD, Bossaert LL; EuReCa ONE Collaborators. EuReCa ONE-27 Nations, ONE Europe, ONE Registry: a prospective one month analysis of out-of-hospital cardiac arrest outcomes in 27 countries in Europe. *Resuscitation* 2016;**105**:188–195.
3. Chan PS, McNally B, Tang F, Kellermann A, Group CS. Recent trends in survival from out-of-hospital cardiac arrest in the United States. *Circulation* 2014;**130**:1876–1882.
4. Benjamin EJ, Blaha MJ, Chiuve SE, Cushman M, Das SR, Deo R, de Ferranti SD, Floyd J, Fornage M, Gillespie C, Isasi CR, Jiménez MC, Jordan LC, Judd SE, Lackland D, Lichtman JH, Lisabeth L, Liu S, Longenecker CT, Mackey RH, Matsushita K, Mozaffarian D, Mussolino ME, Nasir K, Neumar RW, Palaniappan L, Pandey DK, Thiagarajan RR, Reeves MJ, Ritchey M, Rodriguez CJ, Roth GA, Rosamond WD, Sasson C, Towfighi A, Tsao CW, Turner MB, Virani SS, Voeks JH, Willey JZ, Wilkins JT, Wu JH, Alger HM, Wong SS, Muntner P; American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart Disease and Stroke Statistics-2017 update: a report from the American Heart Association. *Circulation* 2017;**135**:e146–e603.
5. Hasselqvist-Ax I, Riva G, Herlitz J, Rosenqvist M, Hollenberg J, Nordberg P, Ringh M, Jonsson M, Axelsson C, Lindqvist J, Karlsson T, Svensson L. Early cardiopulmonary resuscitation in out-of-hospital cardiac arrest. *N Engl J Med* 2015;**372**:2307–2315.
6. Kragholm K, Wissenberg M, Mortensen RN, Hansen SM, Malta Hansen C, Thorsteinsson K, Rajan S, Lippert F, Folke F, Gislason G, Køber L, Fonager K, Jensen SE, Gerds TA, Torp-Pedersen C, Rasmussen BS. Bystander efforts and 1-year outcomes in out-of-hospital cardiac arrest. *N Engl J Med* 2017;**376**:1737–1747.
7. Weisfeldt ML, Sitlani CM, Ornato JP, Rea T, Aufderheide TP, Davis D, Dreyer J, Hess EP, Jui J, Maloney J, Sopko G, Powell J, Nichol G, Morrison LJ. Survival after application of automatic external defibrillators before arrival of the emergency medical system: evaluation in the resuscitation outcomes consortium population of 21 million. *J Am Coll Cardiol* 2010;**55**:1713–1720.
8. Valenzuela TD, Roe DJ, Nichol G, Clark LL, Spaite DW, Hardman RG. Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. *N Engl J Med* 2000;**343**:1206–1209.
9. Ringh M, Jonsson M, Nordberg P, Fredman D, Hasselqvist-Ax I, Håkansson F, Claesson A, Riva G, Hollenberg J. Survival after public access defibrillation in Stockholm, Sweden—a striking success. *Resuscitation* 2015;**91**:1–7.
10. Claesson A, Herlitz J, Svensson L, Ottosson L, Bergfeldt L, Engdahl J, Ericson C, Sandén P, Axelsson C, Bremer A. Defibrillation before EMS arrival in western Sweden. *Am J Emerg Med* 2017;**35**:1043–1048.
11. Fredman D, Ringh M, Svensson L, Hollenberg J, Nordberg P, Djärv T, Hasselqvist-Ax I, Wagner H, Forsberg S, Nord A, Jonsson M, Claesson A. Experiences and outcome from the implementation of a national Swedish automated external defibrillator registry. *Resuscitation* 2018;**130**:73–80.
12. Karlsson L, Malta Hansen C, Wissenberg M, Møller Hansen S, Lippert FK, Rajan S, Kragholm K, Møller SG, Bach Søndergaard K, Gislason GH, Torp-Pedersen C, Folke F. Automated external defibrillator accessibility is crucial for bystander defibrillation and survival: a registry-based study. *Resuscitation* 2019;**136**:30–37.
13. Deakin CD, Shewry E, Gray HH. Public access defibrillation remains out of reach for most victims of out-of-hospital sudden cardiac arrest. *Heart* 2014;**100**:619–623.
14. Hansen SM, Hansen CM, Folke F, Rajan S, Kragholm K, Ejlskov L, Gislason G, Køber L, Gerds TA, Hjortshøj S, Lippert F, Torp-Pedersen C, Wissenberg M. Bystander defibrillation for out-of-hospital cardiac arrest in public vs residential locations. *JAMA Cardiol* 2017;**2**:507–514.

15. Holmén J, Herlitz J, Ricksten SE, Strömsöe A, Hagberg E, Axelsson C, Rawshani A. Shortening ambulance response time increases survival in out-of-hospital cardiac arrest. *J Am Heart Assoc* 2020;**9**:e017048.
16. Bogle BM, Rosamond WD, Snyder KT, Zègre-Hemsey JK. Case for drone-assisted emergency response to cardiac arrest: an optimized statewide deployment approach. *N C Med J* 2019;**80**:204–212.
17. Pulver A, Wei R, Mann C. Locating AED enabled medical drones to enhance cardiac arrest response times. *Prehosp Emerg Care* 2016;**20**:378–389.
18. Boutilier JJ, Brooks SC, Janmohamed A, Byers A, Buick JE, Zhan C, Schoellig AP, Cheskes S, Morrison LJ, Chan TCY; Rescu Epistry Investigators. Optimizing a drone network to deliver automated external defibrillators. *Circulation* 2017;**135**: 2454–2465.
19. Claesson A, Bäckman A, Ringh M, Svensson L, Nordberg P, Djärv T, Hollenberg J. Time to delivery of an automated external defibrillator using a drone for simulated out-of-hospital cardiac arrests vs emergency medical services. *JAMA* 2017; **317**:2332–2334.
20. Sanfridsson J, Sparrevik J, Hollenberg J, Nordberg P, Djärv T, Ringh M, Svensson L, Forsberg S, Nord A, Andersson-Hagiwara M, Claesson A. Drone delivery of an automated external defibrillator—a mixed method simulation study of bystander experience. *Scand J Trauma Resusc Emerg Med* 2019;**27**:40.
21. Cheskes S, McLeod SL, Nolan M, Snobelen P, Vaillancourt C, Brooks SC, Dainty KN, Chan TCY, Drennan IR. Improving access to automated external defibrillators in rural and remote settings: a drone delivery feasibility study. *J Am Heart Assoc* 2020;**9**:e016687.
22. Rosamond WD, Johnson AM, Bogle BM, Arnold E, Cunningham CJ, Picinich M, Williams BM, Zègre-Hemsey JK. Drone delivery of an automated external defibrillator. *N Engl J Med* 2020;**383**:1186–1188.
23. Van de Voorde P, Gautama S, Momont A, Ionescu CM, De Paepe P, Fraeyman N. The drone ambulance [A-UAS]: golden bullet or just a blank? *Resuscitation* 2017;**116**:46–48.
24. Zègre-Hemsey JK, Bogle B, Cunningham CJ, Snyder K, Rosamond W. Delivery of automated external defibrillators (AED) by drones: implications for emergency cardiac care. *Curr Cardiovasc Risk Rep* 2018;**12**:25.
25. Mermiri MI, Mavrovounis GA, Pantazopoulos IN. Drones for automated external defibrillator delivery: where do we stand? *J Emerg Med* 2020;**59**:660–667.
26. Ringh M, Rosenqvist M, Hollenberg J, Jonsson M, Fredman D, Nordberg P, Järnbert-Pettersson H, Hasselqvist-Ax I, Riva G, Svensson L. Mobile-phone dispatch of laypersons for CPR in out-of-hospital cardiac arrest. *N Engl J Med* 2015; **372**:2316–2325.
27. Claesson A, Fredman D, Svensson L, Ringh M, Hollenberg J, Nordberg P, Rosenqvist M, Djarv T, Österberg S, Lennartsson J, Ban Y. Unmanned aerial vehicles (drones) in out-of-hospital-cardiac-arrest. *Scand J Trauma Resusc Emerg Med* 2016;**24**:124.
28. Berglund E, Claesson A, Nordberg P, Djärv T, Lundgren P, Folke F, Forsberg S, Riva G, Ringh M. A smartphone application for dispatch of lay responders to out-of-hospital cardiac arrests. *Resuscitation* 2018;**126**:160–165.
29. Priori SG, Blomström-Lundqvist C, Mazzanti A, Blom N, Borggrefe M, Camm J, Elliott PM, Fitzsimons D, Hatala R, Hindricks G, Kirchhof P, Kjeldsen K, Kuck KH, Hernandez-Madrid A, Nikolaou N, Norekvål TM, Spaulding C, Van Veldhuisen DJ; ESC Scientific Document Group. 2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: the Task Force for the Management of Patients with Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death of the European Society of Cardiology (ESC). Endorsed by: association for European Paediatric and Congenital Cardiology (AEPC). *Eur Heart J* 2015;**36**:2793–2867.
30. Olasveengen TM, Mancini ME, Perkins GD, Avis S, Brooks S, Castrén M, Chung SP, Considine J, Couper K, Escalante R, Hatanaka T, Hung KKC, Kudenchuk P, Lim SH, Nishiyama C, Ristagno G, Semeraro F, Smith CM, Smyth MA, Vaillancourt C, Nolan JP, Hazinski MF, Morley PT; Adult Basic Life Support Collaborators. Adult basic life support: 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. *Circulation* 2020;**142**:S41–S91.
31. Strömsöe A, Afzelius S, Axelsson C, Södersved Källestedt ML, Enlund M, Svensson L, Herlitz J. Improvements in logistics could increase survival after out-of-hospital cardiac arrest in Sweden. *J Intern Med* 2013;**273**:622–627.