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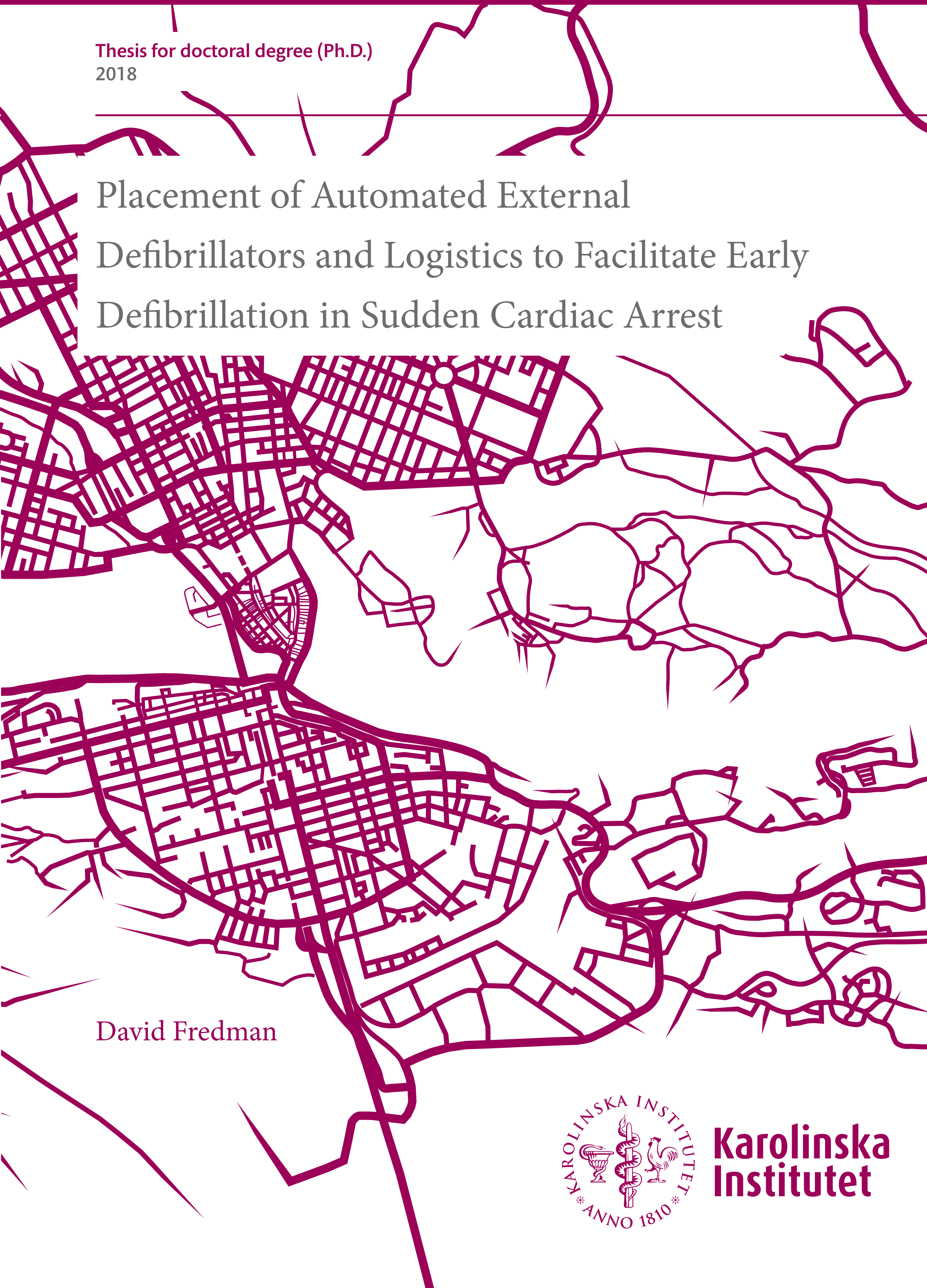
Placement of Automated External Defibrillators and Logistics to Facilitate Early Defibrillation in Sudden Cardiac Arrest



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PLACEMENT OF AUTOMATED EXTERNAL DEFIBRILLATORS AND LOGISTICS TO FACILITATE EARLY DEFIBRILLATION IN SUDDEN CARDIAC ARREST

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Placement of Automated External Defibrillators and Logistics to Facilitate Early Defibrillation in Sudden Cardiac Arrest

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So, learn from them, my son. There is no end to the crafting of many books, and too much study wearies the body.

Ecclesiastes 12:12

För övrigt, min son, låt varna dig! Det finns ingen ände på det myckna bokskrivandet, och mycket studerande gör kroppen trött.

Predikaren 12:12

//To my daughters.

ABSTRACT

Background and aim

Out-of-hospital cardiac arrest (OHCA) is a leading cause of death in many western countries. Much effort is put in to measures to improve survival. Early cardiopulmonary resuscitation (CPR) and the use of an automated external defibrillator (AED) significantly increase the chance of survival. In 2016, 5,312 cases of OHCA were reported to the Swedish Register for Cardiopulmonary Resuscitation (SRCR), but only 577 (11%) survived to 30-days. The bystander CPR rate in Sweden is high (73%), and AEDs are widely spread in all parts of the country; however, the use of public AEDs is low. If the use of AEDs could be increased, more patients could be saved.

The aim of this thesis was to investigate, in four separate studies, how logistics and placement of AEDs can help facilitate early defibrillation.

Methods and results

Study 1 A prospective study at five emergency dispatch centres in Sweden where dispatchers were given access to the Swedish AED registry and had instructions to refer callers to nearby AEDs in cases of suspected OHCA. Of 3,009 suspected OHCA calls over seven months, only 200 occurred within 100 metres of an AED, and in only two cases did dispatchers referred callers to a nearby AED. AED accessibility (opening hours of the venue) and the fact that the callers often were alone on the scene, were identified as barriers for referral.

Study 2 A retrospective analysis of AED installation sites and locations of OHCA in public locations in Stockholm. We used renowned geographic information system (GIS) analyses and a freely available dataset of land use (Urban Atlas). Incidence of OHCA in public locations in “residential areas” was similar to “non-residential” but AED installation was significantly higher in “non-residential areas”.

Study 3 An explorative study to investigate the feasibility of using unmanned aerial vehicles (UAV)/Drones to transport AEDs to decrease time to defibrillation. The study included live test flights of a UAV system as well as retrospective GIS analysis of suitable locations for installation of UAVs equipped with AEDs for maximum coverage of OHCA.

Study 4 An overview of the Swedish AED registry (SAEDREG) shows a two-fold increase of registered AEDs since 2013 and that the majority (45%) of the n=15,849 AEDs are placed in offices/workplaces. In a select region of Sweden, a survey was directed to the owners of all n=218 AEDs that focused on AED functionality and reasons for not registering the AED in SAEDREG. An additional n=94 AEDs were found through customer registries from AED vendors. AED functionality was high in both groups. Owners of AEDs not registered in SAEDREG was often unaware of the national AED registry or stated difficulties with the registration process as the main cause for not registering AEDs in SAEDREG.

Conclusions

Dispatch centres have the potential to refer callers to nearby AEDs at an early stage in OHCA but may need supporting training and software.

There is a mismatch between where public OHCA occur and where AEDs are located. Most AEDs are found in offices and workplaces whereas most OHCA occur in residential areas.

Drones have the potential to transport AEDs and compensate for prolonged ambulance response time, especially in rural areas.

A high quality national AED register is important for increasing general awareness within the community, thus facilitating early defibrillation in OHCA; however, many AEDs are non-registered or discarded in the validation process.

Key words Out-of-hospital cardiac arrest, GIS, Automated External Defibrillator, AED, Defibrillation

LIST OF SCIENTIFIC PAPERS

1. Fredman D, Svensson L, Ban Y, Jonsson M, Hollenberg J, Nordberg P, Ringh M, Rosenqvist M, Lundén M, Claesson A.
   Expanding the first link in the chain of survival–Experiences from dispatcher referral of callers to AED locations
   Resuscitation 2016 Oct;107:129-34

2. Fredman D, Haas J, Ban Y, Jonsson M, Svensson L, Djarv T, Hollenberg J, Nordberg P, Ringh M, Claesson A.
   Use of a geographic information system to identify differences in automated external de brillator installation in urban areas with similar incidence of public out-of-hospital cardiac arrest: a retrospective registry-based study
   BMJ Open. 2017 Jun 2;7, 1-9

3. Claesson A, Fredman D, Svensson L, Ringh M, Hollenberg H, Nordberg P, Rosenqvist M, Djarv T, Österberg Ö, Lennartsson J, Ban Y.
   Unmanned aerial vehicles (drones) in out-of-hospital-cardiac-arrest.
   Scand Journal of Trauma, Resuscitation and Emergency Medicine. 2016 Oct 12;24(1):124

4. Fredman D, Ringh M, Svensson L, Hollenberg J, Djärv T, Hasselqvist-Ax I, Wagner H, Forsberg S, Nord A, Jonsson M, Claesson A.
   Experiences and Outcome from the Introduction of a National Swedish Automated External Defibrillator Registry.
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List of abbreviations

ACLS	Advanced cardiac life support
AED	Automated External Defibrillator
AHA	American Heart Association
CA	Cardiac arrest
CPR	Cardiopulmonary resuscitation
CRF	Case report form
CVD	Cardio Vascular Disease
ECG	Electrocardiogram
EMS	Emergency Medical System
ERC	European Resuscitation Council
EuReCa	The European registry of cardiac arrest
GIS	Geographic information System
ICD	Implantable cardioverter defibrillator
IHCA	In-Hospital Cardiac Arrest
ILCOR	International Liaison Committee on Resuscitation
IP	International Protection Marking
OHCA	Out-of-Hospital Cardiac Arrest
PAD	Public Access Defibrillation
PCI	Percutaneous coronary intervention
PEA	Pulseless electric activity
SCA	Sudden Cardiac Arrest
SAEDREG	Swedish AED Registry
SRC	Swedish Resuscitation Council
SRCR	Swedish Registry for Cardiopulmonary Resuscitation
STEMI	ST-segment elevation myocardial infarction
T-CPR	Telephone assisted Cardiopulmonary resuscitation
TTM	Targeted temperature management
UA	Urban Atlas
UAV	Unmanned aerial vehicle
UK	United Kingdom
US	United States
VT	Ventricular tachycardia
VF	Ventricular fibrillation
WHO	World Health Organisation

1 INTRODUCTION

Cardiac arrest is common and lethal, but many victims can be saved by taking timely actions like Cardiopulmonary resuscitation (CPR) and early use of an automated external defibrillator (AED).

CPR is an easy skill to learn, and tens of thousands of CPR courses are held every year. It takes only a few hours to learn and with yearly refreshers, virtually anyone can be prepared to save a life anywhere at any time just by using their bare hands. Evidence of these assertions can be seen throughout society, and the rate of Bystander CPR is high in Out-of-hospital cardiac arrests (OHCA).

AEDs are also highly effective lifesavers, but they are employed much less frequently than CPR. The numbers of AEDs sold and installed in Sweden and most other countries every year is increasing, but their rate of use remains low. Low survival rates in OHCA reflect these facts.

AEDs are not cheap to buy and their functionality relies upon maintenance and upkeep. Batteries run out; electrodes get old and lose their function. Additionally, if the need for an AED arises, someone must know where to find one and be able to get it to the victim, fast!

1.1 CARDIAC ARREST

1.1.1 Definition

A cardiac arrest (CA) is usually defined as, "…the cessation of cardiac mechanical activity, confirmed by the absence of a detectable pulse, unresponsiveness and apnoea (or agonal, gasping respirations)".[1]

The prefix "sudden" is used to describe that the CA is unexpected and without obvious warning signs. In cases of sudden cardiac arrest (SCA), the circulation of blood and oxygen suddenly ceases due to the loss of mechanical heart function. The patient momentarily loses consciousness and inevitably dies if no resuscitation attempts are made.

The meaning of sudden has been debated. In general, it can be defined as a CA within one hour of symptoms.[2]

The term In-hospital cardiac arrest (IHCA) refers to CA cases that occur within a hospital environment while Out-of-Hospital cardiac arrest (OHCA) refers to those that occur outside of a hospital environment, in society.

1.1.2 Incidence

From a global perspective, cardiovascular disease (CVD) is the number one cause of death. It is accountable for 40% of all deaths in patients under 75 years.[3] The World Health Organisation (WHO) estimates that 17.7 million people died from CVD in 2015.[4]

OHCA is often the first symptom of CVD.[5] With CVD being the leading cause of OHCA and OHCA affecting nearly over 350,000 people every year in Europe, OHCA is a major public-health concern in the western world.[6 7]

Incidence is defined as the occurrence rate of a condition for a population at risk. In most countries and regions, the incidence of OHCA and outcome of OHCA victims are monitored and recorded in OHCA registries. The European registry of cardiac arrest (EuReCa) was established in 2007 by the European Resuscitation Council (ERC) in order to create an overview of European OHCA incidence and outcome.[8]

Incidence of OHCA varies between countries and regions. In 2016 the EuReCa reported an OHCA incidence ranging from 28 to 244 cases per 100,000 inhabitants in a one-month material of 10,682 OHCA cases in 27 European countries.[9]

Previous studies have estimated that 37/100,000 inhabitants suffer OHCA annually in Europe and 52/100,000 are affected by OHCA annually in the US.[10 11] Through 2017 the regional incidence of OHCA in Sweden varied from 30 to 72 cases per 100,000 inhabitants.[12]

OHCA mortality is high, and successful resuscitation is uncommon. The EuReCa-ONE study that included data from 27 European countries showed a 5-30% survival to hospital discharge.[9]

The varying incidence and survival rates can probably be explained by epidemiological differences in the population at risk, such as occurrence of CVD and age. In addition, geographical, and cultural factors may play a vital role for those in whom resuscitation is initiated. The extent to which "do-not-resuscitate" orders apply in a given society may also play a vital role in incidence and survival rates, as may the gap between which patients are included in OHCA registries and which are not.

1.2 CHARACTERISTICS

To compensate for regional and national differences in how characteristics and outcome of OHCA is reported, a uniform system for reporting was created in 1990.[13] The unified reporting template is called "the Utstein template", named after the Utstein Abbey in Norway where leading researchers first met in 1990. The template has since been revised twice and is widely adopted.[14 15]

In Sweden, as in many other countries, the national quality registry for OHCA is based on the variables defined in the Utstein template. The Swedish Registry for Cardiopulmonary Resuscitation (SRCR) is described in detail under section 4.1.1.

1.2.1 Causes of OHCA

Since 2014 the origin of OHCA is divided in to *medical* and *non-medical* in the Utstein template[16], but this is not yet widely adopted. In Sweden, a modified Utstein template is used.[12] With CVD as the most common cause of OHCA, OHCA naturally shares other properties associated with risk factors for ischaemic heart disease such as, increasing age, smoking, diabetes and hypertension.[17]

According to the Swedish Registry for Cardiopulmonary Resuscitation (SRCR), approximately 65% of OHCA cases in Sweden have an aetiology of underlying cardiac disease.[12] Internationally, 60-70% of OHCA are believed to be caused by coronary artery disease.[18 19] Non-cardiac causes of OHCA are: asphyxia, pulmonary embolism, trauma, intoxication and drowning.

1.2.2 Age and sex

Among OHCA patients in Sweden, two thirds are male. The median age of OHCA victims is 71 years[12] with more than 50% of patients below the age of 69.[20]

1.2.3 Witness status

If the OHCA is seen or heard by another person, it is considered a witnessed OHCA. The OHCA can be witnessed by a bystander, which is the case in about two thirds of all OHCA, or by emergency medical system (EMS) personnel which happens in about 15% of all OHCAs.[12]

1.2.4 Rhythm

The initial rhythm in OHCA is determined by using an automated external defibrillator (AED), a manual defibrillator, or an electro cardiograph (ECG). Four heart rhythms characterize an OHCA; they are further categorized in *shockable* and *non-shockable rhythm* in both larger materials and in the individual OHCA case.

1.2.4.1 Shockable rhythms

Pulseless ventricular tachycardia (VT) and ventricular fibrillation (VF) are *shockable rhythms* that can be converted to normal heart rhythm by an electrical shock from an AED. An acute ischaemic episode as myocardial infarction or a previous ischaemic event leaving scars in the myocardium are among the conditions that can trigger VF[21], and VF is closely associated to CVD.

The first recorded rhythm is the strongest independent factor for survival in OHCA. If a rhythm of VT or VF is present on the first ECG as initial rhythm, the patient's chance of surviving the event is significantly increased compared to when a non-shockable rhythm is present.[22 23 24 25] Herlitz et al. (2005) showed a six-time increase in survival in OHCA patients presenting VF when ambulance arrived.[26]

Studies assessing AED use and defibrillation before arrival of ambulance in OHCA have reported VF rates as high as 50 to 65%.[27 28 29] However, the proportion of OHCA cases with VT/VF as the first registered rhythm has been declining over the last decades in most parts of the world[10 30 31 32] and with the strong dependency of time from collapse to initial rhythm assessment[23], the increasing response time for ambulances in Sweden may be a contributing factor.[12] Weisfeldt et al.(2010), found that VF rates remain high (64%) if recorded with an AED at the time of the emergency call and that declining VF rates were related to an increase in unwitnessed cases as well as patients having OHCA at home.[27]

The overall medication strategy with increasing use of beta-blockers for heart disease patients and more patients being in end-stage disease are suggested explanations of decreasing VF rates.[33] Also, the increasing use of implantable cardioverter defibrillators (ICD) in patients could contribute since these patients may already have been shocked by these implanted defibrillators when help arrives.[34 35]

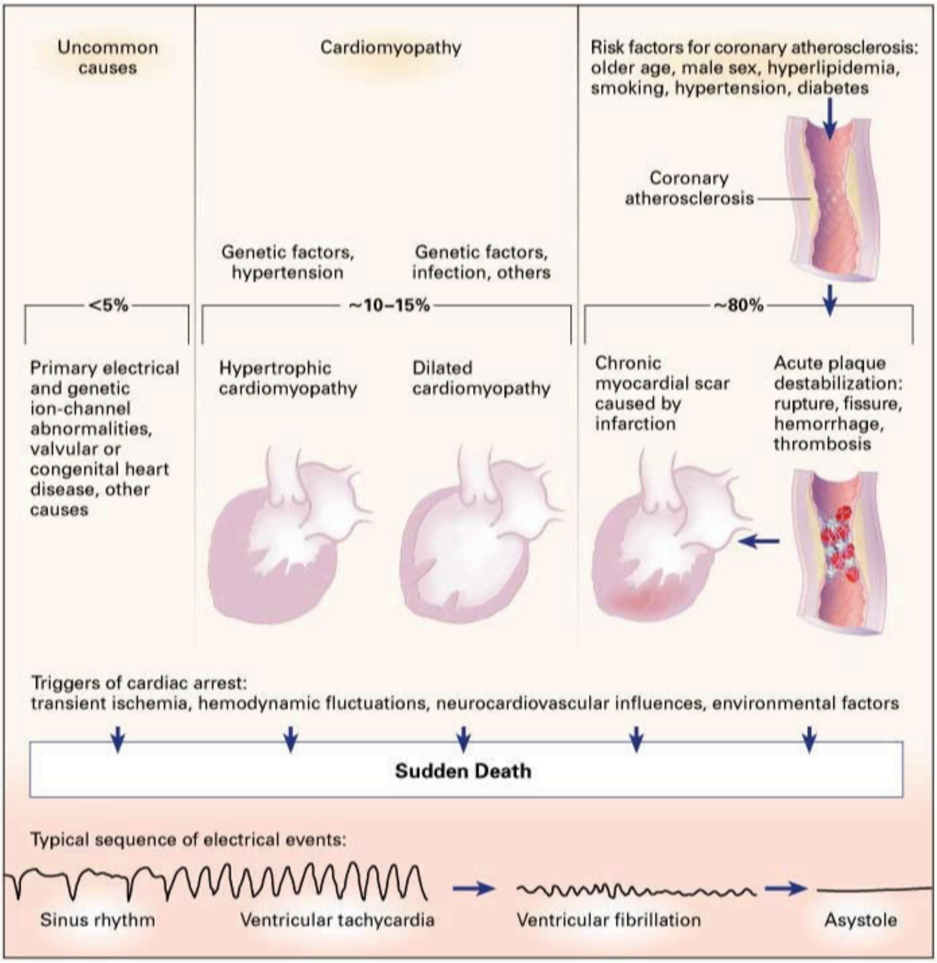

Figure 1. *The figure shows the pathophysiology and epidemiology of sudden death from cardiac causes. It also shows the two shockable rhythms - ventricular tachycardia & ventricular fibrillation and one of the non-shockable rhythms – asystole. (Reproduced with permission from Huikuri, H. et al. 2001, © Massachusetts Medical Society.)*

1.2.4.2 Non-shockable rhythms

Non-shockable rhythms are pulseless electrical activity (PEA) and asystole. These cannot be converted to normal heart rhythm with an AED or manual defibrillator. Asystole is considered a sign of a dying heart and lacks electrical activity on an ECG. It is associated with prolonged duration of OHCA and a very poor outcome prognosis.[36] Asystole is often considered to have been preceded by VF that has deteriorated over time.[21]

PEA presents an organized and adequate rhythm on an ECG, but the contractibility of the heart is either lost or inadequate to maintain a palpable pulse. This is often associated with non-cardiac causes of OHCA such as trauma, asphyxia, intoxication, pulmonary embolism and hypovolemia. OHCA survival from PEA as initial rhythm is low.[37 38]

1.2.5 Location

The location of the OHCA is stated by the ambulance crew performing resuscitation attempts and reporting the case post-event. The most common location for OHCA patients is home where 60-80% of all cases occur.[39 40]

The definition of OHCA incidence location is based on where the ambulance crew finds the victim. According to an update of the Utstein resuscitation registry template from the International Liaison Committee on Resuscitation (ILCOR), the following data options are suggested: *home/residence; industrial/workplace; sports/recreation event; street/highway; public building; assisted living/nursing home; educational institution; other; unknown/not recorded*.[41]

Location of the OHCA plays a great role in outcome because many characteristics that affect outcome vary between locations. OHCA in public locations has been associated with a threefold greater chance of survival than OHCA in patient's home.[20] According to 10-year data of n=38,877 OHCA from Sweden, 69% of OHCA occurred in patients' homes. The second most common location for OHCA in Sweden and the most common in public locations was in streets where 7.2 % of the cases occurred.[12]

In cases where the OHCA occur in a public location: the EMS response time is shorter; the collapse is more often witnessed; there are higher rates of bystander CPR, and AEDs are more commonly accessible.[27 40 42] Compared to public incidence, OHCA victims in a home environment are older, have more co-morbidity affecting outcome and the collapse is less often witnessed which affects both bystander CPR rates and AED use negatively.[40 42]

A recent study with multivariate analysis of factors associated with 30-day survival in n=8,804 OHCA patients in Sweden showed an odds ratio of 0.69 if the OHCA occurred in a patient's home.[43]

Socioeconomic factors on a neighbourhood level seem to be affecting OHCA incidence as well as bystander CPR rates.[44] Furthermore, it has been shown that OHCA incidence is higher in low-income neighbourhoods and that patients are less likely to receive bystander CPR in low-income neighbourhoods than in high-income areas.[45 46] Exploring methods for primary prevention to avoid OHCA in the first place is an important area of research.

1.2.6 Outcome

Measuring and comparing survival in OHCA is difficult and may be subject to bias. Survival rates are expressed as the fraction of patients suffering a defined condition (OHCA) in whom treatment is initiated (EMS attempted resuscitation). Since likelihood of survival is low, the number and characteristics of patients in whom resuscitation attempts are initiated may have significant impact on survival rates. Despite difficulties in comparing survival rates, there are several factors that are repeatedly found to be associated with increased chance of survival in OHCA patients. The most important factors associated with increased survival are: if the OHCA is witnessed, if bystander CPR is initiated, if the time from arrest to call for help and arrival of EMS is short, and if a shockable rhythm is present on first ECG.[47] The cause of the arrest is also important. In patients with a non-cardiac aetiology (i.e. respiratory failure, drug overdose, non-traumatic bleeding, sepsis, electrolyte abnormalities and drowning), outcome after OHCA is less favourable.[48] Also, as described above, patients suffering OHCA at home have a worse prognosis then patients suffering an OHCA in public.[40]

In the following section the most important factors for increased survival in OHCA are further explored in the "chain of survival" concept.

1.3 TREATMENT OF OHCA - THE CHAIN OF SURVIVAL

Successful resuscitation in OHCA is possible with timely actions and depends on several aspects as highlighted in the chain of survival.

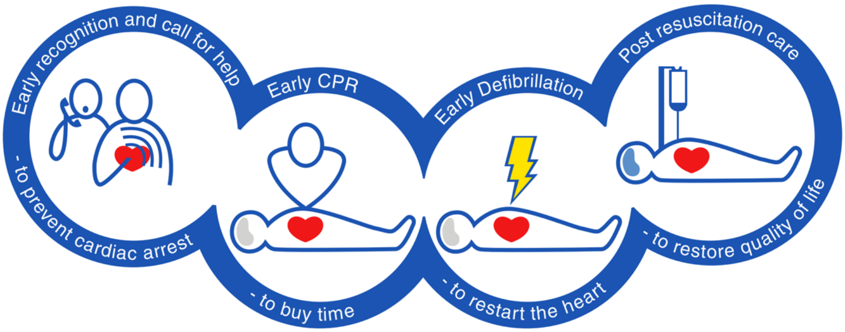

Figure 2. *The chain of survival as described in the European Resuscitation Council guidelines 2015.* [7]

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The chain of survival, established in a statement from the American Heart Association (AHA) in 1995 [49], emanates from decades of research in the field of resuscitation and highlights key elements that affect OHCA survival.

1.3.1 Early recognition and call for help

The first and perhaps most important link actually includes prevention of CA through early identification of potential medical needs and risk of CA. This includes seeking medical attention or calling 112 (emergency services phone number) for chest pain or other cardiac related symptoms to enable ambulance resources to arrive even before the CA occurs.[47 50-53]

The first link also includes identification of a CA by witnesses of the collapse or by the call taker at the dispatch centre. As stated earlier a CA is defined as an individual being unresponsive and not breathing or with abnormal breathing, a definition that is generally taught in CPR courses all over the world. International research has shown that the faster someone calls 112 after OHCA the better the outcome.[22 50 54]

So, if you find a person unconscious and not breathing normally, call 112 for help!

When placing a call to 112 in Sweden, the call taker at the dispatch centre will ask what has happened and focus on the victim's unresponsiveness and breathing to identify to identify or rule out a potential CA as soon as possible.

1.3.2 Early CPR

In the second link, the focus is to buy time by providing assisted circulation and oxygenation of the blood in the form of cardio pulmonary resuscitation (CPR) i.e. chest compression and ventilation. In retrospective analyses the survival benefits of early onset of CPR has been shown repeatedly.[26 53 55 56 43 57]

International consensus on CPR guidelines from the International Liaison Committee on Resuscitation (ILCOR) has been published on a five-year basis since 2000; in Europe this is done through the European Resuscitation Council (ERC).[58] Focus has somewhat shifted over the years from the more drug and ventilation focused approach with a 2:15 ventilation-to-compression ratio in the early 2000s to an increased focus on uninterrupted assisted circulation in the 2005 guidelines.[59] The 30:2 ratio of compressions to ventilations was launched alongside a pedagogical approach involving one mannequin per student. In 2010 focus on uninterrupted high quality CPR continued in the ERC guidelines[60], and AED was part of the Swedish course curriculum. The 2015 guidelines[7] emphasized the role of the "first resuscitation team" i.e. the dispatcher supporting callers in giving high-quality telephone CPR. The current European resuscitation guidelines for adults published in 2015 recommend 30 chest compressions with a depth of at least 50mm but no more than 60mm at a rate of 100-120/minute followed by two rescue breaths. However, if the bystander is unwilling to perform rescue breaths, applying only chest compressions is advocated and recommended by dispatchers.[7]

Multiple mechanisms, including positive hemodynamic effects are associated with the increase in survival from CPR by chest compressions[61] and high quality chest compressions without interruptions increase thoracic pressure[62] and has shown improved hemodynamic in experimental models.[63]

CPR performed by a witness, spouse or anyone outside the dispatched emergency organisation is commonly referred to as Bystander-CPR. Trained emergency medical dispatcher that instruct the caller in how to perform CPR through the telephone, (T-CPR) has shown to reduce the time to start of CPR[64 65], improve bystander CPR rate[66 67] and improve outcome in OHCA.[66 68 69] T-CPR is reportedly only offered to a small proportion of callers.[70] Callers' unwillingness to participate, callers disconnecting the call, or callers not being directly with the patient are barriers to performing T-CPR[71-73]

1.3.3 Early Defibrillation

This link in the chain of survival and the treatment suggested is exclusively limited to OHCA presenting a *shockable rhythm* i.e. VT/VF. To restart the heart an electric shock (defibrillation) can be delivered from an Automated External Defibrillator (AED). Early delivery of electric shock in this context indicates before arrival of the ambulance. An AED is safe to use and effective even when used by untrained non-medical laypersons.[74]

Time is of the essence and the chance of a successful defibrillation decrease for every minute without CPR or use of an AED.[75]

A witness, bystander or alerted first responder can use the self-adhesive electrodes of the AED to analyse the heart rhythm and if necessary, deliver a shock when advised by the AED to restore a normal rhythm and circulation. It is well established that early use of an AED significantly increases the chance of survival in OHCA and in the ERC guidelines from 2015 the importance of interaction between the dispatcher and caller including not only T-CPR but also to dispatch AEDs.[7]

Figure 3. *Community response saves lives. The latest guidelines from the European Resuscitation Council stress the importance of interaction between caller and dispatch centre for improving survival in OHCA. © Elsevier 2015.* [7]

1.3.4 Post-resuscitation care

In the fourth link, advanced cardiac life support (ACLS) and interventions provided by ambulance are included. This includes securing airways through endotracheal intubation or insertion of a laryngeal mask and intravenous or intraosseous drug treatments and can also include manual defibrillation. The 2015 ERC guidelines[76] also include in-hospital post-resuscitation treatment algorithm in the fourth link as:

- Immediate coronary angiography and percutaneous coronary intervention (PCI) to revasculate patients with an ECG presenting ST-section elevation myocardial infarction (STEMI)
- Therapeutic hypothermia or targeted temperature management (TTM) to improve neurological function
- Prognostication of individual cases before deciding on withdrawal of care.

In this thesis, the main focus is on the first and third link in the chain of survival, but it is important to point out that this chain is only as strong as its weakest link.

1.4 AUTOMATED EXTERNAL DEFIBRILLATORS

1.4.1 History of defibrillation and the AED

An Automated External Defibrillator (AED) is a portable device designed to analyse heart rhythms and appropriately deliver a potentially lifesaving defibrillation to the heart in case of a CA. The success of the implementation and use of AEDs is closely tied to the fact that they are safe, effective and easy to use even by untrained civilians or lay responders.[77 78 78]

Manual defibrillators have been in use in medicine since the 1960s.[61] Interestingly, the idea to use electricity to restore the natural rhythm of the heart dates back another 200 years. In 1775, a Dr. Squire reportedly defibrillated a young girl with something resembling a defibrillator using a capacitator with wooden handles and copper connectors.[79]

Since the development of the first ones in the 1970s[80], AEDs have grown smaller in size and bigger in functionality, that spans from the earliest models that required special trollies or vehicles to be moved up to today's portable lightweight devices.[81] Much of the recent improvements in AEDs have been driven by technological breakthroughs in battery technology and smaller electronic components. This has led to smaller, lighter AEDs with greater stand-by time. AEDs have also become easier to use and requires no special training.[74 82]

The most common models of AED are semi-automated in that after applying the electrodes an ECG analysis is carried out automatically. Then if a potential shockable heart rhythm is detected the shock can be delivered by manually pushing a button on the device. Fully-automated AEDs are available that differ from semi-automatic AEDs only in that they deliver a shock automatically after detecting a shockable rhythm. A fully automated AED will give a voice and sound alert prior to shock to advise bystanders. Studies have shown that safety errors from AED users were reduced and that general safety was not compromised when fully automated AEDs were used compared to semi-automatic.[83 84]

Recently AEDs are growing more rugged to better comply to the needs of diverse environments, particularly for placement outdoors. Now AEDs with IP classification up to IP55 is common. This means that they are dust protected and can withstand water jets up to 12.5 litre/minute for a minimum of three minutes.[85]

AEDs are built to be easy to use with strict quality measures to assure high functionality. They use advanced algorithms for rhythm analysis, but there have been reports of malfunctioning devices. Studies analysing the quality of rhythm analysis have been carried out. One found that all VF cases were correctly detected by AEDs in the study, but there was a slight discrepancy between machines concerning VT detection.[86] Another study showed that of 148 shockable episodes 16% were missed by the AED while of 689 non-shockable episodes the AED suggested a shock in 4% of cases.[87]

A study looking at AED rhythm analysis and shock using two different AEDs showed significant difference in sensitivity and specificity between the AEDs. The authors suggested that manufacturers improve the rhythm detection algorithms and recommended medical staff be aware of the potential shortcomings of AEDs.[88]

1.4.2 The concept of Public Access Defibrillation (PAD)

Public access defibrillation (PAD) as a concept was formulated back in late 1990´s [89-91] and promoted availability of AEDs in different levels of society. The PAD concept introduced placing AEDs in public locations where they could be used by trained or untrained civilian bystanders. In 2000, Valenzuela et al. published a landmark study from casinos in Nevada that focused on security officers trained in CPR who used an AED to save victims. They reported a 74% survival rate in cases where victims were defibrillated within the first three minutes of a witnessed collapse.[92]

In a large multicenter-prospective, randomized controlled trial by Hallstrom et al. (2004) community units such as shopping malls, large office buildings, recreational facilities and residential areas were randomly assigned to a system where lay volunteers employed at a given community unit were trained in CPR or in CPR and the use of an AED.[77]

This study is one of the largest OHCA trials in which more than 19,000 volunteer responders from 993 community units in 24 US regions participated. The two study groups had similar unit, baseline and volunteer characteristics. Among 128 OHCA in the CPR+AED group there were 30 survivors compared to 15 survivors amongst 107 in the CPR only group. They concluded that this massive education effort and intervention to facilitate early defibrillation within a structured response system increased the number of survivors to hospital discharge after out-of-hospital cardiac arrest in public locations.[77]

In this legendary PAD trial, the numbers of adverse events were few, and no inappropriate shocks were delivered by the AEDs. Therefore, it was also concluded that laypersons trained in CPR and AED can use AEDs safely and effectively. [77]

Since then the concept of PAD and making AEDs more available has been widely adopted. It has also been repeatedly shown that improvements in outcome in OHCA; both survival and neurological status at discharge, are associated with use of AEDs in public locations.[27 93 94-96 97-100] In a study from Seattle, Washington, US., the proportion of OHCA cases defibrillated through PAD only represented 1.33% (n=50) but with a 50% rate of survival to discharge.[101]

A 15-fold increase in AED use and a dramatic increase in survivor figures with favourable outcome was shown in a large Japanese PAD study with over 43,000 OHCA cases, and they attributed these improvements to PAD.[98] A similarly positive outcome was also reported in Stockholm, Sweden, where a recent publication showed a 70% survival in OHCA where the patient was defibrillated by lay bystanders using a publicly available AED. [102] With less favourable conditions for successful resuscitation in residential areas, ERC recommends active implementation of PAD programs in public areas.[7]

1.4.3 High incidence sites of OHCA

When estimating the possible effects of a PAD programme expected incidence of OHCA is important to take in consideration for maximum efficiency. In the European guidelines, the ERC states that AEDs should be placed in locations with an expected OHCA incidence of one every five years.[7] However, incidence of OHCA is not easy to calculate. It is important, for instance, to decide how big the area is that will be considered a “location”. A study analysing 2,037 OHCA in the city of Columbus, Ohio, US., covering an area of roughly 575 km2 used a method to cluster OHCA locations. Five clusters of OHCA were identified covering 1,028 OHCA in 76 of the 245 census tracts within the city limits. So, 50% of the OHCA over five years occurred in 31% of the census tracts in the city.[103] However, the respective distance between the OHCA was not determined, neither was the size of the clusters.

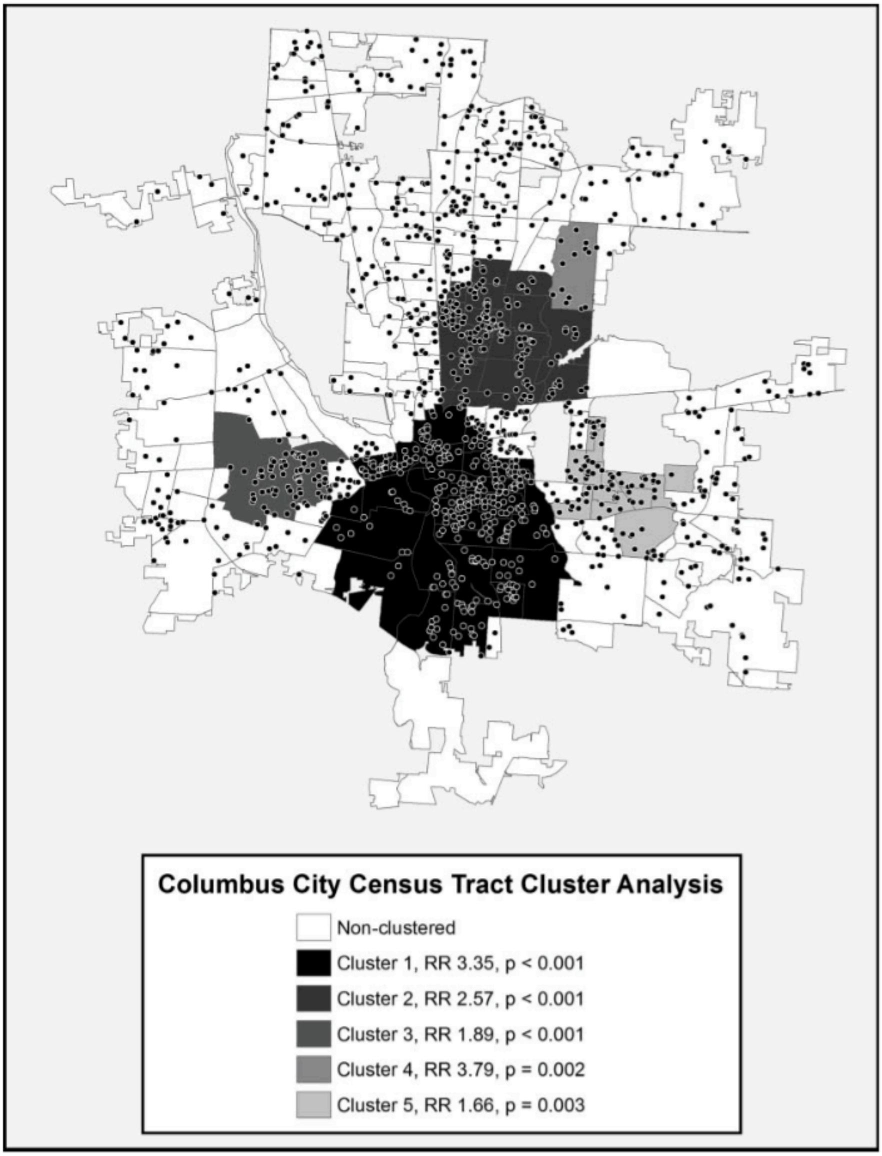


Figure 4. *Locations of cardiac arrests and high-risk clusters of census tracts in Columbus, Ohio. RR=relative risk. © 2012, Taylor & Francis group Prehospital Emergency Care. Warden, C. et al.*

A similar approach was used to identify clusters of OHCA in the city of Rochester, New York, U.S. Over four years 537 cases were plotted using geographic information system (GIS), and census defined block groups were used as the map layer including population density. To calculate OHCA incidence density they used a GIS method called Kernel analysis to account for OHCA incidents at a given location compared to incidents in surrounding areas. Here they identified two cluster areas, one with nine OHCA cases and one with six.[104]

With the objective of identifying census tracts not only with high-risk of OHCA but also low incidence of bystander CPR, Sasson et al. (2012) used three different GIS methods for cluster analysis on 1,632 cases of OHCA in Columbus, Ohio and identified five areas with high-risk of OHCA that appeared in all three analyses.[105]

Numerous publications over the years has used GIS in attempt to identify high-risk locations of OHCA and to identify locations for installing AEDs.[42 89 90 103 105-123 124] But still there is no consensus on what method to use.

To further understand the complexity of these recommendations for AED installation it is worth mentioning that there used to be a discrepancy in standard for suggesting suitable locations for AED installation between the American Heart Association (AHA) and the European Resuscitation Council (ERC). The AHA recommended AEDs be installed where one OHCA occurred every five years while the ERC recommended they be installed in locations where one OHCA occurred every two years.[125 126]

1.4.4 AED installation

The 2015 ERC guidelines state that AEDs should be placed in, "…public places with a high density and movement of citizens such as airports, railway stations, bus terminals, sport facilities, shopping malls, offices and casinos…" (Perkins et al./resuscitation 95 (2015) 81-99 Page 91).[7]

AED installations in areas where the expectancy of OHCA is one per five years is considered to be cost effective compared to other medical interventions[127 128] and is supported in the ERC guidelines.[126]

The numbers of AEDs installed in communities is increasing, and with those increasing numbers it would be reasonable to believe that AED use would increase; however, this has not been the case. In Sweden the national AED registry holds some 16,000 AEDs[12], and the numbers have doubled over the last years.(Fredman, study 4, unpublished) Despite this uptick, AED use still remains low and of a cohort of 8,698 OHCA cases in Sweden, only 1.8% were defibrillated using a public AED.[129]

This situation is also reported from many other locations around the world. A British study showed that despite a regional PAD program AEDs were out of reach for many OHCA victims, and many public locations had no AEDs available. In the cases where AEDs were present, they were only used in a small proportion of the OHCA.[130]

Another study analysing the correlation between OHCA incidence and strategic AED installation reported a poor association between them and no AEDs being in the top three incident locations (private homes, skilled nursing facilities & assisted living facilities), and surprisingly no OHCA occurring in the top three location types for AED installation (community pools, public buildings & schools).[121]

In Japan, the number of AEDs in public has increased at a tremendous rate from over 297,000 in 2011 to over 360,000 available in 2012.[131 132] This number was estimated to exceed 500,000 in 2014. Murakami et al. (2014) described a significant increase in public-access AED use over a six-year period. However, the actual cases defibrillated are low and from a cohort of 9,453 public OHCA in Japan, only 17 occurred in railway stations and 23 in sports facilities in which 7 (41.3%) and 13 (56.5%) respectively were defibrillated.[131]

Despite numerous attempts to identify neighbourhood characteristics beneficial for AED installation using retrospective analysis of OHCA incidence,[90 117 133] mathematical models,[111] demographic characteristics[42] and geographic information systems (GIS)[104] hard evidence on the most suitable location to install AEDs is yet to be presented.

A study from Denmark saw that strategic placement of AEDs in limited areas of a city could cover a substantial proportion of the OHCA cases but also saw a paradox in AED placement. Amongst 104 AEDs placed by local or political initiatives, none were used. The authors concluded that AED installation driven by local or political initiatives lead to AED installation primarily in low-incidence areas.[118]

Perhaps it is reasonable to believe that the initiator of an AED being installed in a local community would choose the location based on media coverage and corporate social responsibility rather than likelihood of use.

In the ERC guidelines, AEDs are also suggested to be placed in densely populated areas[126], but no recommendation is given on the level of density.

In the large PAD trial from 2004 by Hallstrom et al. that established the PAD concept and proved its efficacy, it is worth mentioning that of the 496 units included where employees received training in CPR+AED only 15.5% of the locations were in residential areas.[77]

International guidelines encourage AEDs to be installed in public areas such as shopping malls, sports facilities, train and bus stations and offices. However, in most examples AED deployment is not centrally controlled or directed.[134] Zijlstra et al. (2014) found that only about 40% of all the AEDs in Holland were managed by a municipality and placed in "strategically situated places".[135]

Strategic placement in conjunction with uninterrupted AED accessibility are critical criteria in identifying effective PAD programmes.[97] In the US. there are laws mandating that AEDs be placed in all federal buildings.[136 137]

A review article on the topic of PAD programs suggested continuous implementation of PAD but stressed AED placement to be prioritised based on community characteristics and public health impact and also to be integrated with local EMS/ambulance systems.[99]

1.4.5 AED availability

The importance of AED installation in PAD programs has been established, but the convenient availability of AEDs is equally important as it directly influences the efficacy of deployed AEDs.

With AEDs primarily being installed in public locations that have a very definitive accessibility tied to their hours of operation – like train stations, offices, shopping malls and sporting arenas – this may limit AED availability.

A Danish study found that AED coverage decreased by 53.4% at the time of day when 61.8% of all cardiac arrests occur in public locations.[138] In Canada researchers found a 21.5% decrease of actual AED coverage when accounting for the hours of operation of the buildings in which the AEDs were placed.[115] Accessibility to the AED owning locations clearly does not always coincide with the time of incidence of OHCA. Therefore, strategic placement must be combined with uninterrupted AED accessibility in order for PAD programmes to be effective.

In a study from the UK., proximity and availability of AEDs was a major reason for low AED use[130], and in a study in this thesis we saw that not only was AED proximity to a suspected OHCA a major reason for dispatchers not referring callers to nearby AEDs in Sweden, but AED accessibility at the time of suspected OHCA was as well.[72]

A novel approach is to look for AED locations with good coverage of OHCA and that have either favourable access hours or unlimited access. A study from Canada identified business and municipal locations like bank machines and coffee shops, naturally with favorable access hours, to cover many of the retrospective OHCA in Toronto.[114] In a study from Pittsburgh, Pennsylvania, US., researchers created a model using postal collection boxes as suggested locations for AED installation. They saw that this would cover a greater part of the city compared to existing AED locations (55% vs 30%) and increase AED coverage in residential areas (62% vs 27%).[123]

A novel way to overcome the problem of AED installation and accessibility as well as a means to decrease delay to defibrillation in areas with prolonged ambulance response time may be the use of unmanned aerial vehicles (UAV) or drones as a delivery device.

Through GIS-modelling it is possible to detect areas with prolonged ambulance response times and focus drone systems there. Besides our study 3 as presented in this thesis[139], Pulver et al. (2016) and Bouitillier et al. (2017) has presented GIS-models calculating placement of drones delivering AEDs for Salt Lake City, Utah, US. and Toronto, Canada respectively.[140] [141] Drones have also been used to locate victims of OHCA due to drowning[142] and are predicted to be used by ambulance organisations to a greater extent in the future for delivery of medical products.[143] [144]

2 AIMS

The overall aim of this thesis and the four studies within it was to better understand AED location in the context of AED use and to seek to improve logistics to increase AED use.

2.1 SPECIFIC AIMS

2.1.1 Study 1

To investigate to what extent an application displaying nearby AEDs and their availability made available on maps at dispatch centres contributed to dispatchers referring callers in suspected OHCA cases to nearby AEDs, as suggested by ERC.

2.1.2 Study 2

To investigate if the distribution of public AEDs in the Stockholm Region followed the incident locations of OHCA occurring in public locations.

2.1.3 Study 3

Here the aim was twofold: 1) to use two different GIS models to describe the potential benefit of a drone/UAV system in order to decrease response time i.e. defibrillation, in OHCA, and 2) to investigate the practical use of a drone/UAV system to deliver AEDs to describe safety and efficacy of this new method.

2.1.4 Study 4

To describe the process of developing a national AED registry and furthermore, in a select region, to analyse differences between registered and non-registered AEDs.

3 ETHICAL CONSIDERATIONS

In the World Medical Association (WMA) Helsinki declaration revised in 2013, it is stated that physicians and others involved in human research shall act in in the patients best interest and with the health of the patient as the prime consideration.[145]

In medical research, informed consent from the individual or next of kin is a vital part of including patients in clinical trials or scientific projects, but individuals suffering an OHCA are for obvious reasons unable to give consent because they are unconscious.

In paragraph 30 of the Helsinki declaration, this is mentioned. Here it is stated that if the condition preventing consent is a necessary characteristic of the research and if the specific reasons for involving patients in the study without consent is stated in research protocol the individual may be enrolled anyway. However, as soon as possible, i.e. when gaining consciousness and recovering, the patient shall give consent to remain in the research.[145]

With a mortality rate in OHCA of 90% and a risk for this group of patients to be discriminated from the prospect of improved prognosis of survival, there are several humanitarian and scientific reasons to include OHCA victims in scientific studies.

In the Swedish Registry for Cardiopulmonary Resuscitation (SRCR), data is entered by the ambulance crew after finalising resuscitation attempts. If the outcome is favourable and the patient survives, SRCR officials contact the patient or next of kin and inform them that the patient is included in a national quality register. If they do not accept this they can opt out and have their data removed.[12] When researchers apply for data from SRCR, they shall present an ethical approval from the regional ethical committee to be granted access.

The regional ethics committee in Stockholm has approved all studies in this thesis.

4 MATERIALS AND METHODS

4.1 DATA COLLECTION

In this section, the sources of data for this thesis and the four studies are described.

Study 1

Here data was collected from SOS Alarm AB dispatch centres including the audio files from the actual emergency calls concerning suspected OHCA in order to determine to what extent dispatchers referred callers to nearby AEDs. Data on time of call and the geographic location for each suspected OHCA was also apprehended in order to analyse proximity to AEDs in SAEDREG and time of incidence to match with AED availability.

Study 2

Here we used data from Swedish Registry for Cardiopulmonary Resuscitation (SRCR) concerning OHCA in public locations i.e. reported by ambulance crew as not occurring in patient's home. This data-set was joined with data from the Swedish AED registry (SAEDREG) on AEDs in the same region, Stockholm County. We displayed this on maps with the urban atlas data-set which contains data on land use in urban areas in the European union.

In order to make geographic analysis, we obtained x/y coordinates from dispatch centres' (SOS Alarm AB) local records concerning these OHCA. Locations of AEDs in the same region were apprehended from SAEDREG. To be able to objectively define the urban areas we downloaded the Urban Atlas data set from European Commission's Global Monitoring of Environment and Security. This is a dataset with objectively defined areas of urban and rural landscape that is freely available for most major urban regions in the European Union.

Study 3

In this study, we used historical cases of OHCA from SRCR occurring in Stockholm county. For the live test flights, a UAV system specifically designed for this purpose was used that allowed us to evaluate drone delivery of AED from take-off to application of AED electrodes on a CPR manikin.

Study 4

Data was apprehended from SAEDREG concerning the total number of registered AEDs per annum as well as the region and location as stated by the owner. To analyse differences between AEDs registered in SAEDREG and non-registered AEDs we created a survey and performed telephone interviews with AED owners in the region of Gotland from June to October in 2017.

4.1.1 The Swedish Registry for Cardiopulmonary Resuscitation

The Swedish registry for Cardiopulmonary resuscitation (SRCR), was founded in 1990 and is one of over 100 national quality registries in Sweden that contain important healthcare data and provide a unique opportunity to monitor results and quality.[146]

From the beginning SRCR solely gathered data on OHCA but since 2005, it also includes in-hospital cardiac arrest (IHCA) cases. The SRCR is supported by the Swedish Resuscitation Council and has been a valuable source for numerous publications in the field of OHCA research.

Since 2008 OHCA is reported through a web-based online report protocol where the ambulance crew responding to OHCA calls enter data of all patients where resuscitation attempts i.e. CPR is started and/or patient is defibrillated, either by a bystander, ambulance personnel or any other entity. In the 2017 annual report, over 87,800 cases of OHCA are included.[12 20]

Reporting of OHCA is based on voluntary participation from ambulance providers in Sweden. According to a recent validation, nearly 100% of the reporting of ambulance treated OHCA in Sweden is acquired through retrospective audit and follow up of local ambulance registers.[20] Reporting in SRCR follows the Utstein template and includes: age, gender, aetiology, location, if the collapse was witnessed, initial rhythm, first defibrillation among other variables, including time of ambulance arrival and fist time of 112 call (emergency services).[20]

Strömsoe et al. identified a missing report rate of 25% within the SRCR in 2013. In non-reported cases of OHCA, CPR was more commonly initiated as compared to retrospectively reported cases (65% vs 60%), and the mean age was significantly lower (67 years vs. 69 years). The 30-day survival rate was higher among patients who were reported retrospectively (9.2% vs. 11.9%). No differences were seen between groups regarding gender, time of day, year of OHCA, witnessed status or initial rhythm.[20]

Historically, outcome from resuscitation in SRCR is reported as 30-day survival, and a cerebral performance (CPC) score of 1 – 5 is reported for survivors where CPC 1 is deemed as good cerebral performance and CPC 5 as brain dead.[13] Recently, SRCR has been performing a structured follow up on patient reported outcome measures of OHCA survivors retrospectively from 2013.

All patient data in study 2 and 3 are from the Swedish Registry for Cardiopulmonary Resuscitation (SRCR).

4.1.2 Dispatch centre data

In Sweden a centralised alarm number, 112, is used and all emergency calls are primarily handled by SOS Alarm AB dispatch centres. Each incoming 112 call is logged and recorded and when the call takers identify a medical emergency, they create a case file which is assigned a unique mission ID. This mission ID includes a prefix that identifies the unique case and the regional dispatch centre that the case belongs to so they can be geographically distinguished.

All actions from the call taker, assisting nurses and ambulance dispatchers are logged and time stamps are created throughout the duration of the call. These time stamps include "time of 112 call", "ambulance assigned", "vehicle stop" at patient's location and "patient delivered at hospital". These time logs are also included in the actual reports reporting to SRCR.

At the emergency medical dispatch centre, data is stored concerning all 112 calls. This data includes the severity of the call according to Swedish medical index, recordings of the actual call, timestamps for all actions taken like when the call was received, and all the actions carried out by the call taker and ambulance dispatcher. Because the emergency dispatch centre also dispatches ambulances, the data also contains the address and geographic location of the place where the ambulance is sent. We paired this geographic data with the matched locations of calls concerning suspected cardiac arrests to SOS Alarm AB with locations of AEDs.

In study 1, we prospectively gathered calls handled by the call takers as concerning suspected cardiac arrests in one of SOS Alarm ABs administrative regions with four dispatch centres covering six counties in Sweden that include 3.8 million inhabitants.

Data on emergency calls concerning suspected OHCA, their locations and the audio files were permitted from local registries at SOS Alarm AB emergency dispatch centres. Analysis of the audio files took place on location at only one SOS Alarm AB dispatch centres for legal reasons. Only the 200 cases within 100 metres from an AED underwent audio assessment to determine to what extent callers were referred to AEDs and if not, the reasons why.

Geographic location and time of incidence of the suspected OHCA cases were matched with geographic locations and availability of AEDs from SAEDREG. We matched the geographic locations of these incidents with AED locations from SAEDREG to identify adjacent AEDs.

4.1.3 Swedish AED registry

The Swedish AED registry (SAEDREG), initiated in 2009 is a joint venture between the Swedish resuscitation council (SRC)and the Civil defence association with the overall aim to raise awareness of OHCA and AEDs on a national level and to gather information of AEDs in public locations, and to facilitate early defibrillation. This aim is fulfilled by providing AED locations on maps available to the public through websites, data of AED locations provided to dispatch centres[72] and mobile positioning systems.[147]

AED registration in SAEDREG is completed by the AED owner, and the information is entered directly into a form on the internet. The information includes: address (street address, zip code and county/region), type of location of AED installation, and AED availability i.e. access hours. For a more precise location verification, for example in a specific building at an address, the owner is asked to move a calliper icon on a map, thus creating exact x/y coordinates.

4.1.4 Geographic information systems

The term geographic information systems (GIS) generally refers to any information system that store, edit, analyse and/or display geographic information. GIS can be used as a tool for problem solving and decision-making processes, but GIS is most commonly used to visualise data in a spatial environment, i.e. mapping where things are and marking geographic relationships over time or mapping densities, quantities and changes over time.

There are four basic and interdependent subsystems in GIS: 1) Input, 2) Pre-processing, 3) Analysis, and 4) Output.

Input can be in the form of geographic observations that are all represented by geographic coordinates. Pre-processing is the manipulation of input data to relate observations over time to a static (or not) geographic background, i.e. map. Analysis can be virtually anything; a comparison of a phenomenon occurring over time, the number of observations within a certain distance from a point of interest, the travel distance from A to B taking geographical barriers in account. Finally, output is the product of all the previous in the form of maps or graphs that make it comprehendible and relatable.[148]

There are a number of GIS software available for use and for the studies in this thesis Q-GIS, an open source GIS software was used.[149]

In its early years, before the digital GIS as we know today, physicians used to map outbreaks such as the Broad Street cholera outbreak of London in 1854 to track the infectious disease. In this particular case, John Snow, a physician mapped each cholera case and identified an infected water pump on Broad Street as the source of the outbreak.[150]

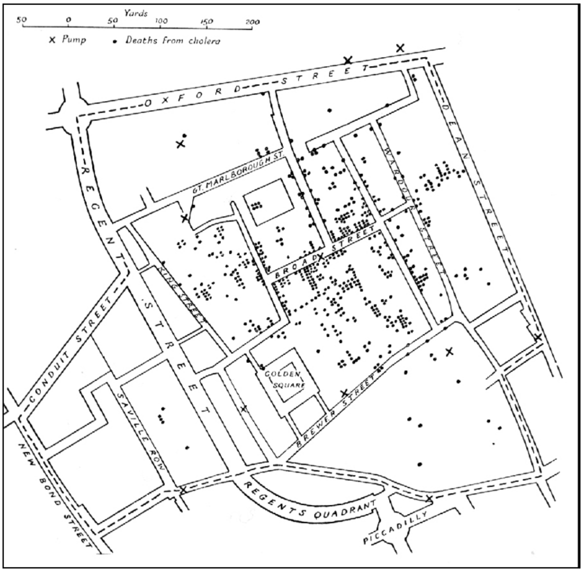


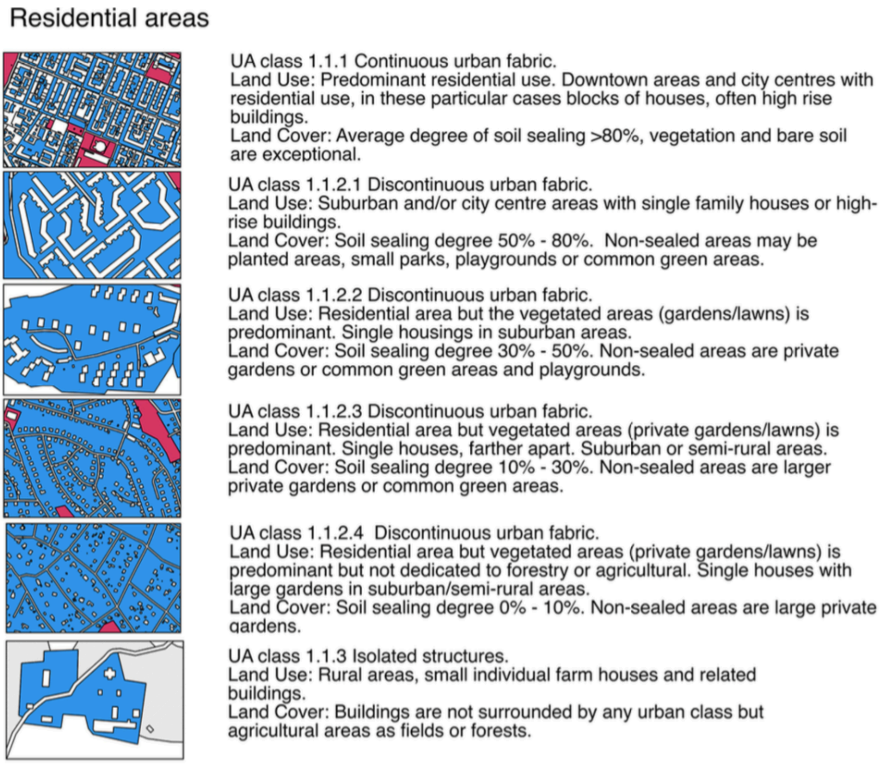
Figure 5. *E.W. Gilbert´s version (1958) of John Snow´s map from 1855 of the Broad Street Cholera Outbreak in London 1854.*

4.1.4.1 *Urban Atlas*

The European Urban Atlas (UA) data set is a part of the European Commission's Global Monitoring of Environment and Security. It provides reliable and comparable high-resolution maps of urban areas in Europe, including all capital cities of European Union member states. UA, primarily intended for inter-comparable and reliable urban planning data, is well-known and widely used in European urban areas.[151-153] Based on high-resolution (2.5 meter) satellite images and supported by reference topography maps, UA contains 19 land use/land cover classes and is provided as freely downloadable datasets.[154 155]

For the analysis of geographic distribution of public OHCA and public AEDs in urban areas of the Stockholm Region, we used the classification "land with human activity, non-agricultural" a term we borrowed from the UA decision matrix. These urban areas were reclassified as either; (1) "residential areas", (2) "non-residential areas" or (3) "other areas" based on their dominant land use and land cover. The definitions and descriptions of the UA subcategories are found in section 4.6. of the mapping guide for UA.[154]

Figure 6 below from *Study 2* show map cut outs and gives a closer description of the reclassification of residential and non-residential areas for easier interpretation of the urban subcategories.



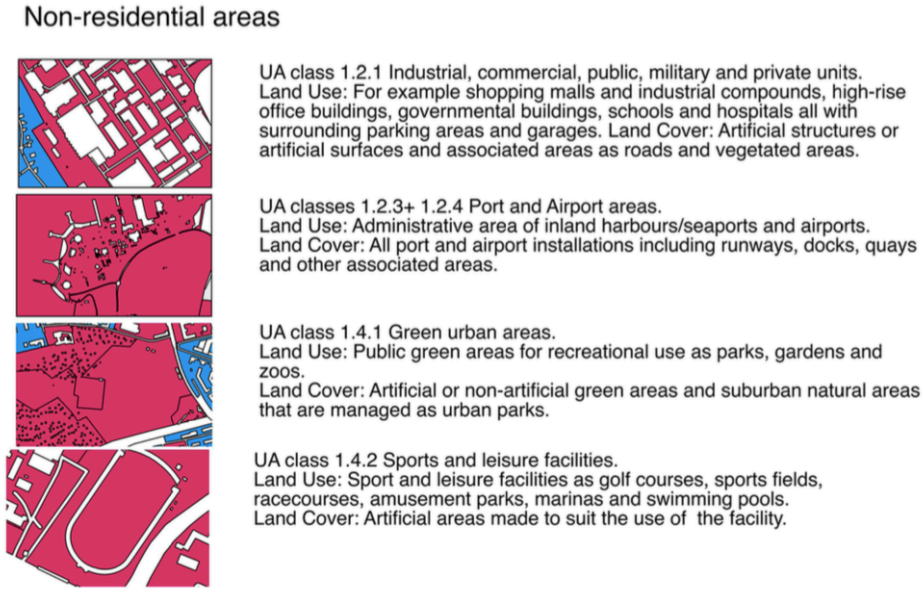


Figure 6. *Description of the Urban Atlas (UA) subcategories creating the residential (R1-R6) and non-residential (NR1-NR4) areas of Stockholm, Sweden including map cut-outs for visualization. The text next to each subcategory includes the original UA subcategory numbering as well as UA land use and land cover description.*

4.2 OVERVIEW OF STUDIES

4.2.1 Study 1

4.2.1.1 Aim

The aim was to investigate to what extent dispatchers referred callers to nearby AEDs when provided with an application that displayed AED locations and availability in real time integrated to dispatch centres' maps.

4.2.1.2 Material & Methods

An application providing call takers and dispatchers with AED locations and accessibility (i.e. access hours) was implemented and integrated at four of SOS Alarm AB's emergency medical dispatch centres in a central region in Sweden. The application imported data from SAEDREG and displayed AED locations and accessibility directly on the map interface used by the dispatchers in their daily work.

Prior to implementation all dispatchers participated in a mandatory on-site education program that taught them how and when to use the AED application. The education program included early identification of OHCA and the importance of early CPR and AED use. It was also stressed that dispatchers should not jeopardize telephone assisted CPR (T-CPR) in the attempt to refer callers to a nearby AED because T-CPR is a standard procedure that is well established as a procedure that increases the odds of survival.[66 67 69 156]

The cases eligible for analysis in this study were identified through the dispatchers' categorization of each call according to the Swedish medical index where suspected OHCA are categorized as "unconscious person, not breathing" and/or "unconscious person with abnormal or agonal breathing".

All emergency calls categorized as above that were handled during the seven-month period 11 February 2014 to 10 August 2014 along with their individual case-ID and geographical locations were apprehended from SOS Alarm AB.

To analyse and determine the suspected OHCA cases relating to AEDs we used a geographical information system (GIS) to compare these two types of locations. This way we could isolate suspected OHCA cases ≤100m of an AED, a distance identified as feasible for AED referral by dispatchers during a three-month run-in period and a distance proposed by literature as close enough for defibrillation within three minutes.[125]

The audio files for the cases ≤100m of an AED were apprehended from SOS Alarm AB officials and were audited at the premises of the SOS Alarm AB dispatch centre in Stockholm to identify cases where dispatchers referred callers to nearby AEDs. The actual recordings of these emergency calls were assessed to determine the location of the suspected OHCA, if the collapse was witnessed, and of course, the rate of AED referral by dispatchers. The assessment also collected other metrics of the case which were all entered into a case report form (CRF). A skilled nurse from SOS Alarm AB assisted in interpretation of dispatch specific matters of the recordings and data outtake.

4.2.2 Study 2

4.2.2.1 Aim

To investigate if the distribution of public AEDs follows the incident locations of public OHCA in urban areas of Stockholm, Sweden.

4.2.2.2 Material & Methods

Data on historical OHCA between January 1st 2012 and December 31st 2014 were apprehended from SRCR and those where the reporting ambulance crew had stated the location of collapse as being in a public location (i.e. not in patient's home) were selected for analysis. The exact locations of these OHCA were identified by accessing SOS Alarm case files and extracting x/y coordinates for them thus making it possible to perform spatial analysis on them. From SAEDREG all publicly available AEDs at December 31st 2013 were selected for matching with OHCA locations.

For spatial analysis of AED and public OHCA locations, we used a modified Urban Atlas (UA) data set of the Stockholm Region downloaded from the European commission's Global Monitoring of Environment and Security. From UA core data sets, we aggregated and reclassified subcategories of urban areas in Stockholm in to two main categories: "residential areas" and "non-residential areas". As the names imply these two categories are differentiated by the dominating use of land and the structures (i.e. buildings) located within them.

4.2.3 Study 3

4.2.3.1 Aim

The aim of study 3 was twofold. First, we wanted to describe the potential benefit of a drone/UAV system to decrease response time (i.e. defibrillation) in OHCA while using two different GIS models. Second, we wanted to investigate the practical use of a drone/UAV system to deliver AEDs and to describe safety and efficacy of this new method.

4.2.3.2 Material & Methods

In investigating the potential benefit of drones to deliver AEDs, we used historical locations of OHCA in the Stockholm Region between 2006-2013. We used GIS software to perform spatial analysis to find optimal UAV placement and created raster layers of Stockholm County. One was created using interpolated values from EMS delay time from SRCR for each OHCA case and where a point density tool was used to count the number of non-crew witnessed OHCA cases of presumed cardiac aetiology within distinct areas in the region. It was thus able to provide a raster layer that represented the density of these OHCA cases.

After that we used the inversed distance weight interpolated tool in the GIS software to create a raster from a point layer. GIS simulations to calculate the arrival time of a UAV carrying an AED were carried out and compared to historical data on ambulance arrival. These simulations were performed on cases in two groups, dividing the location of OHCA to either "urban" or "rural" depending on the land use and population density of the location of OHCA. Manual test flights with an UAV equipped with an AED was performed on selected historical OHCA locations to evaluate three different methods of drone delivery of an AED.

4.2.4 Study 4

4.2.4.1 Aim

The aim of this study was to describe the development of a national AED registry and to analyse the coverage of the registry, AED locations and barriers to registering AEDs.

4.2.4.2 Material & Methods

We relied on four years of data from SAEDREG for analysis and used data from 2013 when the registry was fully digitalised. The data is in the form of an output file with AED location and region of installation for each AED in the registry. We performed year-by-year analysis of AED locations and distribution per region in Sweden as well as comparisons between the years to see the cumulative numbers of AEDs.

A survey was conducted of AED owners in the region of Gotland. 124 were identified from SAEDREG and another 94 from customer records of AED retailers in the region. The survey consisted of a series of questions on AED functionality and CPR education but in the cases of AEDs not registered in SAEDREG, we ask the owner if the decision not to register the AED was intentionally taken or not. If yes, we asked further questions to determine why.

5 RESULTS

5.1 STUDY 1 – EXPANDING THE FIRST LINK OF THE CHAIN OF SURVIVAL

5.1.1 Main results

During the seven-month study period 11 February 2014 to 10 August 2014, n=3,009 emergency calls were categorized as suspected OHCA by dispatchers. Of these calls, 6.6% (n=200) occurred ≤100m from an AED, and the actual recordings of these emergency calls were selected for further analysis concerning AED referral by dispatchers. In two cases (n=2) the dispatcher referred the caller to a nearby AED.

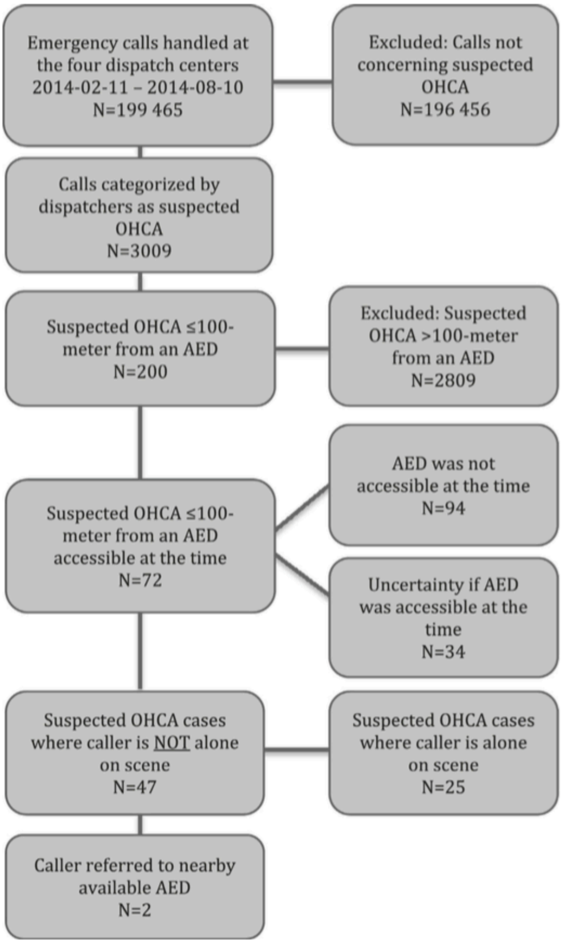


Figure 7. *Flowchart of inclusion of suspected OHCA cases and selection for further analysis. Abbreviations: AED-automated external defibrillator, OHCA-out of hospital cardiac arrest.*

5.1.2 Location of OHCA

According to the assessment of the audio recordings, n=115 of the 200 cases of suspected OHCA occurred in a residential location, i.e. person's homes (57.5%). Of the n=85 suspected OHCA that occurred in public locations, the most common locations were: street 28%, outdoor/park 12%, and public toilet 9%.

Table 1. *Specified locations of suspected OHCA in public location in Study 1.*

Variable	*n*	%
Street	24	28
Outdoor/park	10	12
Public toilet	8	9
Public pool	6	7
Store	5	6
Subway/train station	4	5
Hotel	4	5
Restaurant	4	5
Office	3	4
Shopping mall	3	4
Other	14	15
Total	85	100

Data describes locations of suspected OHCA as described by callers. *Abbreviation*: OHCA – out-of-hospital cardiac arrest.

In the cases occurring in public locations, the rate of witnessed collapse was significantly higher than in residential locations, 56% public vs 18% residential, and the rate of CPR initiated at call start was significantly higher 26% public vs. 4% residential. ($p< 0.05$)

In cases occurring in residential locations, it was more common for the caller to be alone on scene 56% residential vs. 18% public, and it was also more common for the caller of the specific cases to not be at the scene at all.

Table 2. *Characteristics of suspected OHCA* ≤100m from an AED

Variable		Residential location (*n* = 115)		Public location (*n* = 85)		*p*-Value	Total (*n* = 200)	
		n	%	*n*	%		*n*	%
AED ≤100-m accessible	Yes	31	27	41	48	<0.05	72	36
at time of call	Unknown	24	21	10	11		34	17
Victim over 18	Yes	114	99	76[a]	95	0.073	190[a]	97
Caller alone on scene	Yes	59[b]	56	14[c]	18	<0.05	73[b,c]	40
Collapse witnessed	Yes	48	42	61	72	<0.05	109	54
CPR initiated at call start	Yes	5[d]	4	22	26	<0.05	27[d]	14
T-CPR offered	Yes	37	32	28	33	0.909	65	33

Abbreviations: OHCA – out of hospital cardiac arrest, AED – automated external defibrillator, CPR – cardiopulmonary resuscitation, T-CPR – telephone assisted cardiopulmonary resuscitation.
p-Values are calculated between the suspected OHCA in residential vs. public locations. *p*-Value below 0.05 was considered statistically significant.
[a] Missing *n* = 5.
[b] Missing i.e. caller not on scene *n* = 10.
[c] Missing i.e. caller not on scene *n* = 6.
[d] Missing *n* = 1.

5.1.3 AED accessibility

In 36% of the n=200 suspected OHCA calls made ≤100m from an AED, the call occurred within the access hours of the AED. It was more common for AEDs to be accessible at the time of call in cases occurring in public locations, 48% public vs. 27% in residential locations.

5.1.4 AED referral

Of the 200 cases analysed based on proximity to an AED, there were only two (n=2) cases in which dispatchers referred a caller to a nearby AED. These two cases of AED referral occurred in public locations, both railway stations and the callers were on-duty security guards.

5.1.5 Barriers to AED referral

The main reason for dispatchers not referring callers to nearby AEDs, apart from only 200 of the 3,009 suspected OHCA occurring ≤100m from an AED, was AED accessibility. When relating AED access hours with time of call only 72 of the 200 cases occurred within the access hours of the AED. In 35% of the cases where the AED was accessible (25/72), the caller was alone on scene. According to protocol, dispatchers must not refer them to a nearby AED, because it would jeopardise T-CPR.

This was more common in residential locations where the caller was alone on the scene in 56% of the suspected OHCA cases. There were 45 calls where the nearby AED was available and the caller was not alone-on-scene but not referred to nearby AED. The most common reason for this was signs of death or expected death stated by the caller (16%).

Signs of life were also reported by callers in 7% of cases. This is probably because calls concerning suspected OHCA include a thorough interview that may change the initial classification of the call.

Table 3. *Reasons identified for dispatcher not referring callers to AED in eligible cases.*

Variable	*n*	%
No obvious reason identified	24	53
Signs of death/expected death	7	16
Caller not directly at the victims side	5	11
Signs of life	3	7
Stress/language barrier	3	7
Caller hangs up	2	4
Discouraged to act (perform CPR) by dispatcher	1	2
Total	45	100

Describes identified reasons for dispatchers not referring callers to nearby AED in suspected OHCA cases where the nearby AED was available and caller not alone on scene.
Abbreviations: AED – automated external defibrillator, OHCA – out of hospital cardiac arrest.

5.2 STUDY 2 – USE OF A GEOGRAPHIC INFORMATION SYSTEM TO IDENTIFY DIFFERENCES IN AUTOMATED EXTERNAL DEFIBRILLATOR INSTALLATION IN URBAN AREAS WITH SIMILAR INCIDENCE OF OUT-OF-HOSPITAL CARDIAC ARREST; A RETROSPECTIVE REGISTRY-BASED STUDY

5.2.1 Main results

From 1 January 2012 to 31 December, 2014, a total of 804 OHCA occurred in public locations in the Stockholm Region according to ambulance crews reports to SRCR. By 31 December 2013 there were 1,828 AEDs available in public locations in Stockholm County. The incidence of public OHCA was similar in "residential areas" and "non-residential areas", 47.3% vs. 43.4% respectively. However, publicly available AEDs were less common in "residential areas" than in "non-residential areas" 29.4% vs. 68.8% respectively.

5.2.2 Residential versus non-residential areas

The Stockholm region consists of 6,174 km2. After our reclassification of UA land use, we divided the region into three categories: "residential area" 643 km2, "non-residential area" 311 km2, and "other areas" 5,220 km2.

The "residential areas" are areas that contain many buildings and in which the dominant use of land and structures is residential. The six reclassified areas range from "Residential area"1 (R1) to "Residential Area" 6 (R6) with R1 representing densely populated city centres and R6 representing isolated structures in more rural settings. "Non-residential areas" are areas that consist of artificial surfaces (i.e. man-made) where industrial, commercial, leisure and recreational use is predominant. The four reclassifications of "non-residential areas" are: NR1 (industrial/commercial), NR2 (airports), NR3 (green urban areas), and NR4 (sport and leisure facilities).

In the category "other area", the number of OHCA and AED was relatively small, 75 and 33 respectively, and they were not studied further.

5.2.3 Public OHCA incident locations

In locations categorised as "Residential Areas", n= 380 (47.3%) of the total n=804 OHCA occurred in public locations. The highest proportion of OHCA was found in area R3 (12.9%), an area representing suburban villas classified in UA as single housing in suburban areas.

In locations categorised as "non-residential areas", n=349 (43.4%) of the total OHCA occurred. The highest proportion of OHCA was found in NR1 (28.4%) an area classified as "industrial/commercial etc.". This was also the area with the highest incidence of OHCA in the material.

5.2.4 Public AED locations

Of the n=1,828 publicly available AEDs, n=537 (29.4%) were in residential areas and n=1,258 (68.8%) were in non-residential areas.

The largest proportion of AEDs in residential areas was found in R1, where 14.6% of the AEDs were located and in non-residential areas, NR1 had the largest proportion of AEDs with 59%. The area with the least public available AEDs was R6 (isolated structures), an area that also had the fewest public OHCA occurrences.

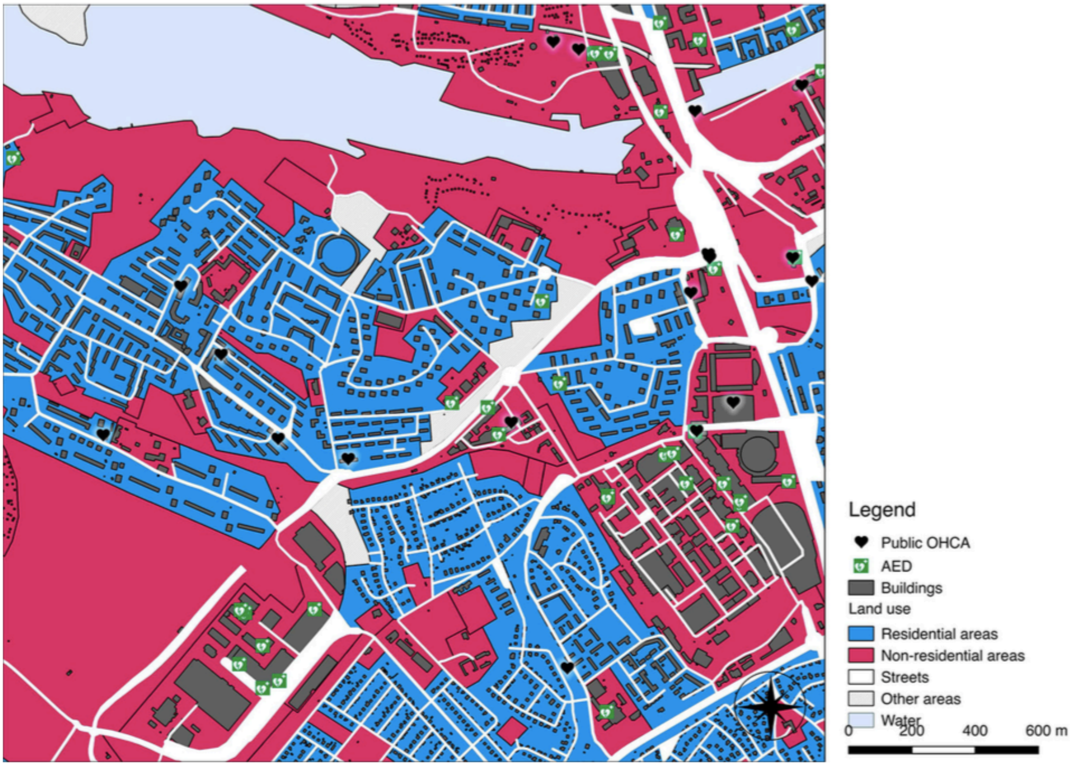


Figure 8. *Close up of an area south-west of central parts of Stockholm. This visualises the mismatch in public OHCA incidence and AED locations between residential and non-residential areas.*

The area with the highest number of publicly available AEDs was NR1 where 59% of the 1,828 AEDs were located. This was also the area in which the highest percentage, 43.4%, of public OHCA occurred. The median distance from OHCA to AED was significantly shorter in "non-residential areas" than in "residential areas", 188m vs 288m respectively ($p<0.001$).

Table 4. *Locations of public out-of-hospital cardiac arrests (OHCA) and automated external defibrillators (AED) in urban areas of Stockholm and characteristics for distance from OHCA to AED, ambulance response time and 30-day survival per classified urban areas*

	Public OHCA	Public available AED	Area	OHCA/100 km^2	AED/100 km^2	Distance OHCA to AED (median)	Ambulance response time (median)	30-day survival
	% (n)	% (n)	km^2	n	n	m	min	%
Residential areas	**47.3 (380)**	**29.4 (537)**	**643**	7.4	**83.5**	**288.4**	**11.0**	**17.8**
R1 (UA 1.1.1 Continuous, SL >80%)	10 (80)	14.6 (267)	6.6	151.5	4045.5	98.7	8.0	NA
R2 (UA 1.1.2.1 Discontinuous Dense, SL 50–80%)	6.7 (54)	4.8 (88)	16.8	39.9	523.8	186.3	10.0	NA
R3 (UA 1.1.2.2 Discontinuous Medium Density, SL 30–50%)	12.9 (104)	3.2 (59)	62.5	20.6	94.4	355	11.0	NA
R4 (UA 1.1.2.3 Discontinuous Low Density, SL 10–30%)	11.7 (94)	3.9 (72)	186.4	6.3	38.6	520.4	13.0	NA
R5 (UA 1.1.2.4 Discontinuous Very Low Density, SL <10%)	5.1 (41)	2.4 (44)	307.4	1.7	14.3	928.9	14.50	NA
R6 (UA 1.1.3. Isolated Structures)	0.9 (7)	0.4 (7)	63.7	1.4	11	1309.1	18.0	NA
Non-residential areas	**43.4 (349)**	**68.8 (1258)**	**310.9**	14	**404.6**	**187.6**	**11.0**	**24.1**
NR1 (UA 1.2.1 Industrial, commercial etc)	28.4 (228)	59 (1079)	119.7	23.7	901.4	141.6	9.50	NA
NR2 (UA 1.2.4 Airports)	2 (16)	1.9 (35)	12	16.7	291.7	139	16.50	NA
NR3 (UA 1.4.1 Green urban areas)	6.1 (6.1)	0.8 (15)	87.6	7	17.1	348.7	12.0	NA
NR4 (UA 1.4.2 Sports and leisure facilities)	7 (56)	7.1 (129)	91.6	7.6	140.8	417.7	11.0	NA
Other areas	**9.3 (75)**	**1.8 (33)**	**5291.7**	0.2	**0.6**	**1217.5**	**16.0**	**10.8**
O1 (UA 2 Agricultural + Semi-natural areas + Wetlands)	3.5 (28)	0.7 (12)	1331.9	0.3	0.9	1087.6	17.0	NA
O2 (UA 3 Forests)	5.8 (47)	1.1 (21)	3959.8	0.1	0.5	1414.6	16.0	NA

Legend. *The table show the Urban Atlas (UA) categories and our reclassification in R1-R6 Residential Areas, NR1-NR4 Non-residential areas and O1&O2=Other areas. Data on OHCA location, ambulance arrival and outcome is from the Swedish registry on Cardiopulmonary Resuscitation and data on AED locations are from Swedish AED registry.*

5.3 STUDY 3 – UNMANNED AERIAL VEHICLES (DRONES) IN OUT-OF-HOSPITAL CARDIAC ARREST

5.3.1 Main results

Of n=7,256 OHCA cases in Stockholm from 2006 – 2013, n=4,385 were non-crew witnessed and of presumed cardiac aetiology. These were included in the GIS model. Based on the density of OHCA cases and ambulance delay, 20 suitable locations for UAVs transporting AED were identified, covering 72% (n=3,165) of the OHCA.

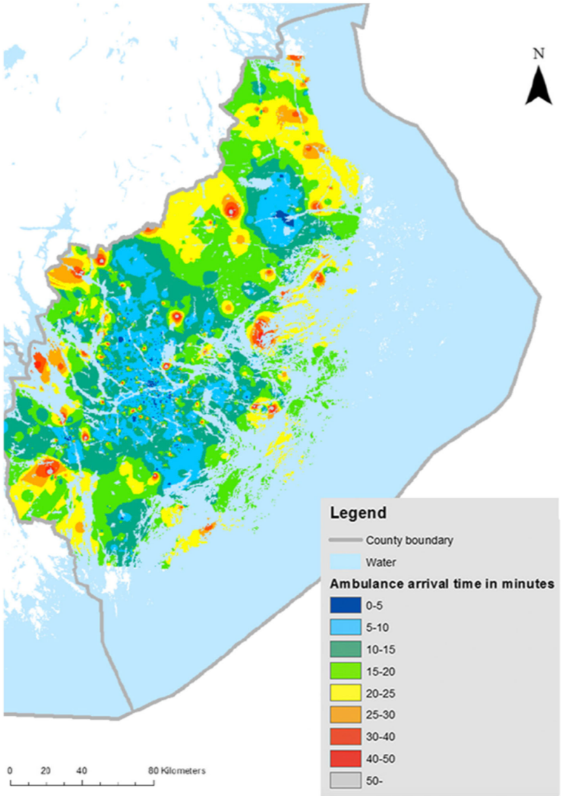


Figure 9. *EMS response time in OHCA, Stockholm Region 2006–2013. Ambulance arrival time in minutes, Stockholm Region 2006–2013. Non-crew witnessed, cardiac etiology, n = 4,385 cases.*

In n=3,041 cases, the incidence location was in urban areas. With a 50/50 weighing of ambulance delay time, i.e. distance and density, of OHCA incidence, 10 suitable locations were identified, primarily in the city centre. Here UAV was predicted to reach the incident location before an ambulance in 32% of cases with a mean time saved (faster-than-ambulance response) of 1.5 minutes.

In n=124 cases, the incidence location was in rural areas. Considering greater ambulance delay time (i.e. distance) and lower density of OHCA incidence, the data model was given an 80/20 weighing. In these cases, a UAV was predicted to reach the location before an ambulance in 93% of the cases, with a mean time saved of 19 minutes.

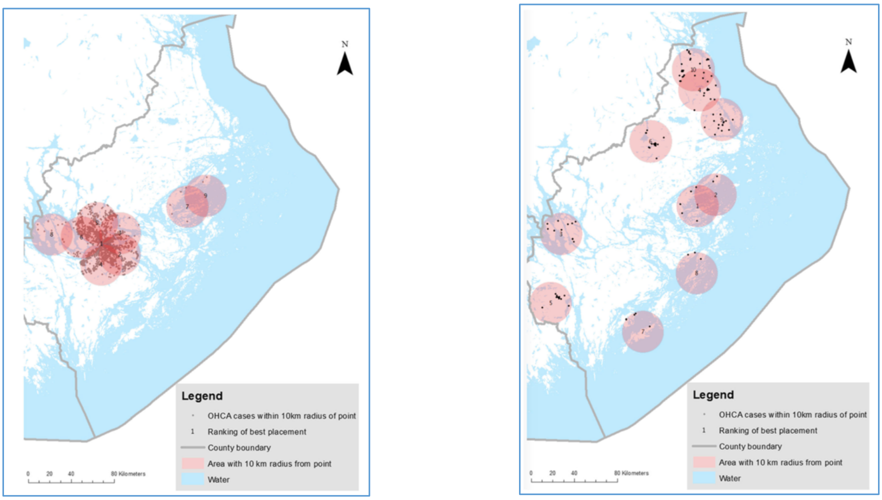


Figure 10. *Optimal placement of UAV, using a 50/50 (left) and an 80/20 (right) weighting alternative with regards to EMS response time and incidence of OHCA. In total, n = 3,041 versus n=124 OHCA cases between 2006–2013 in the Stockholm Region within a 10-km radius from point of optimal placement of UAV. Location #10 coincides with location #1in the left picture and was therefore excluded from visualization in this figure.*

Table 5. *Potential of an UAV/Drone system for delivery of AED in OHCA*

Urban, 50/50 weighting	UAV, simulated maximum delay (min)	EMS, delay (min)[b]	UAV before EMS (min)[b]	UAV before EMS (%)
Location #:				
1 (471,1122)[a]	8,5	8,5 (0–93)	0	30 %
2 (368,864)	8,5	-	-	30 %
3 (250,710)	8,5	8 (0–93)	- 0,5	26 %
4 (323, 621)	8,5	9 (1–77)	0,5	34 %
5 (359,589)	8,5	9 (0–93)	0,5	39 %
6 (293,366)	8,5	10 (0–86)	1,5	44 %
7 (5,0)	8,5	31 (14–44)	22,5	100 %
8 (12,0)	8,5	24 (13–46)	15,5	100 %
9 (3,0)	8,5	32 (18–43)	23,5	100 %
10 (454,1095)	8,5	8 (0–76)	- 0,5	29 %
Total, (2538,5367)				32 %
Rural, 80/20 weighting	UAV, simulated maximum delay (min)	EMS, delay (min) [b]	UAV timesaving (min)	UAV before EMS (%)
Location #:				
1 (5,0)	8,5	31 (14–44)	22,5	100 %
2 (3,0)	8,5	-	-	-
3 (12,0)	8,5	29 (13–46)	20,5	100 %
4 (21,0)	8,5	29 (19–43)	20,5	100 %
5 (14,1)	8,5	30 (11–81)	21,5	93 %
6 (23,1)	8,5	21 (11–62)	12,5	96 %
7 (4,1)	8,5	23 (9–40)	14,5	80 %
8 (3,0)	8,5	38 (6–82)	29,5	100 %
9 (15,1)	8,5	23 (5–41)	14,5	94 %
10 (24,6)	8,5	20 (3–54)	11,5	80 %
Total, (124,10)				93 %

[a]Numbers within parenthesis: (OHCA with UAV arrival before EMS vs OHCA with EMS arrival before UAV). Calculations based on suitable placements using a 50/50 vs an 80/20 weighting scenario, 8.5 min flight-time, UAV in 70 km/h velocity. Several cases are found within one or more UAV-locations, radius of each location 10 km

[b] Mean delay (minutes) from call to arrival of EMS

5.3.2 Drone delivery tests.

To evaluate the appearance of the AED equipped UAV n=13 manual tests of three different methods of AED delivery were performed on select historical OHCA cases in rural settings.

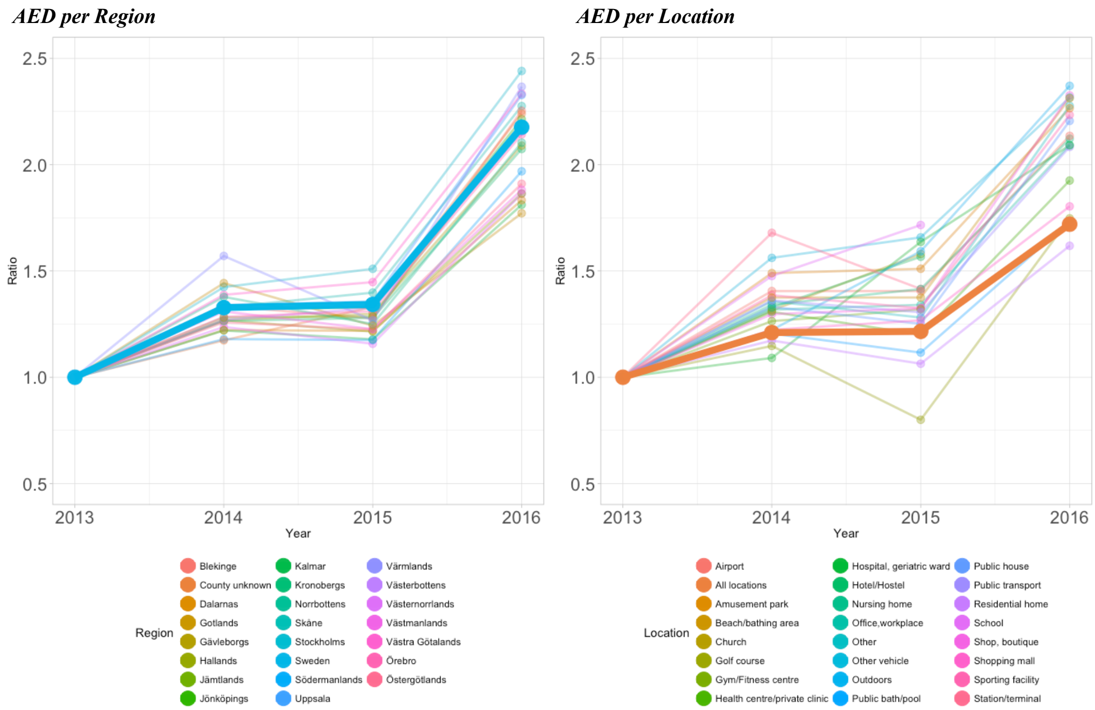
AED delivery was found to be feasible using a latch-release from an altitude of 3-4 meters (n=6) or preferably landing the UAV on flat ground (n=6), with caution taken in regard to bystanders and the spinning propellers of the UAV. These two methods were found to be easy to perform for the pilot and easy and safe for bystanders on the ground. The third method, releasing the AED attached to a parachute, caused uncertainty of where the AED would land. This method was consequently discarded after only one try.

5.4 STUDY 4 – EXPERIENCES AND OUTCOME FROM THE INTRODUCTION OF A NATIONAL SWEDISH AUTOMATED EXTERNAL DEFIBRILLATOR REGISTRY

5.4.1 Main results

From the start of the Swedish AED Registry (SAEDREG) in 2009, 7,287 AEDs were added to it until 1 January 2013. The number of AEDs have doubled the following four years; by 31 December 2016, 15,849 AEDs were registered. The number of AEDs increased in every region in Sweden with the highest increase being in the Västra Götaland Region at 246.1%.

Figure 11. *AED registration from 2013 to 2016 displayed per Region and per Location*



Legend: *Display of the increase ratio of AEDs in Sweden per Region and Per Location with 2013 as year one.*

Table 6. *Distribution of AEDs per County, Sweden 2013 – 2016*

		2013				2016				AED increase Total (n)	AED increase/10 000 inhabitants
County	**Area (Km2)[157]**	**Inhabitants (n)[158]**	**Inhabitants/ Km2 (n)[158]**	**AED (n)**	**AED/10 000 inhabitants**	**Inhabitants (n)[158]**	**Inhabitants/ Km2 (n)[158]**	**AED (n)**	**AED/10 000 inhabitants**	**2013-2016**	**2013-2016**
Stockholm region	6 524,13	2 163 042	331.4	1 163	5	2 269 060	347.8	2 690	12	231%	2.4
Uppsala region	8 189,62	345 481	42.2	185	5	361 373	44.1	405	11	219%	2.2
Södermanland region	6 075,07	277 569	45.7	171	6	288 097	47.4	398	14	233%	2.3
Östergötland region	10 559,43	437 848	41.5	333	8	452 105	42.8	636	14	191%	1.8
Jönköping region	10 436,68	341 235	32.7	458	13	352 735	33.8	1 014	29	221%	2.2
Kronoberg region	8 424,33	187 156	22.2	190	11	194 628	23.1	407	21	214%	1.9
Kalmar region	11 164,69	233 874	21	286	12	242 301	21.7	518	22	181%	1.8
Gotland region	3 134,98	57 161	18.2	70	14	58 003	18.5	124	25	177%	1.8
Blekinge region	2 931,1	152 757	52.1	164	11	158 453	54.1	345	23	210%	2.1
Skåne region	10 967,83	1 274 069	116.2	897	7	1 324 565	120.8	2 041	15	228%	2.1
Halland region	5 427,04	306 840	56.5	265	9	320 333	59	494	15	186%	1.7
Västra Götaland region	23 799,85	1 615 084	67.9	1 153	7	1 671 783	70.2	2838	17	246%	2.4
Värmland region	17 518,8	273 815	15.6	170	6	279 334	15.9	383	14	225%	2.3
Örebro region	8 504,39	285 395	33.6	204	7	294 941	34.7	423	15	207%	2.1
Västmanland region	5 117,69	259 054	50.6	252	10	267 629	52.3	474	18	188%	1.8
Dalarna region	28 029,47	277 349	9.9	275	10	284 531	10.2	504	18	183%	1.8
Gävleborg region	18 118,44	277 970	15.3	201	7.4	284 586	15.7	420	15	209%	2.0
Västernorrland region	21 548,74	242 156	11.2	292	12	245 572	11.4	544	23	186%	1.9
Jämtland region	48 935,42	126 461	2.6	142	12	128 673	2.6	336	28	237%	2.3
Västerbotten	54 664,6	261 112	4.8	193	7	265 881	4.9	416	16	216%	2.3

region											
Norrbotten region	97 238,87	249 436	2.6	223	9	250 570	2.6	439	18	197%	2.0
Region not stated*	NA	NA	NA	121	NA	NA	NA	271	NA	224%	NA
TOTAL	407 311,17	9 644 864	23.7	7 287	8	9 995 153	24.5	15 849	16	217%	2.0

Legend: *Table 6 shows the Area, number of inhabitants, inhabitants per km2 of the 21 counties in Sweden 2013 and 2016 as well as in total for all of Sweden.*[157, 158] *The table also shows the number of AEDs and number of AEDs/10,000 inhabitants in the counties and all of Sweden as well as the total increase of AEDs and increase in AEDs/10,000 inhabitants between 2013 and 2016.*
**Region not stated are AEDs located in locations such as ferries and vehicles where the location is not fixed.*

By 2016 Sweden had 9,644,864 inhabitants. On a national level, the number of AEDs per/10,000 inhabitants doubled from 8/10,000 in 2013 to 16/10,000 in 2016. The largest increase of AEDs/10,000 inhabitants over the four-year period, 2.4, was seen in the Västra Götaland region (7-17/10,000) and the Stockholm region (5-12/10,000) (Table 6).

Upon registration in SAEDREG, the AED owner states the address, including zip code and region, and they also use a calliper tool on the registration website to verify the location and thus creating x/y coordinates. A general increase of AEDs was seen over the years in all locations. In 2016, AEDs were most frequently found in offices and workplaces 45% (n=7,241) followed by shops 7% (n=1,200) and public buildings 6% (n=956).

Table 7. *AED location in SAEDREG 2013 - 2016*

	2013		2014		2015		2016		2013-2016
Location	**(n)**	**%**	**(n)**	**%**	**(n)**	**%**	**(n)**	**%**	**Total increase %**
Office, workplace	3461	46.7%	4561	46.4%	4640	46.7%	7241	44.9%	209%
Shop, boutique (excl. mall)	516	7.0%	669	6.8%	683	6.9%	1200	7.4%	233%
Public house	462	6.2%	638	8.0%	602	6.1%	956	5.9%	207%
Other	470	6.3%	593	6.0%	567	5.7%	1070	6.6%	228%
Sporting facility	428	5.8%	615	6.3%	578	5.8%	1019	6.3%	238%
Health centre, primary care, dentist, private clinic	374	5.0%	489	5.0%	429	4.3%	702	4.4%	188%

Church	283	3.8%	372	3.8%	447	4.5%	720	4.5%	254%
School	250	3.4%	369	3.8%	449	4.5%	711	4.4%	284%
Hotel/Hostel	180	2.4%	239	2.4%	282	2.8%	451	2.8%	251%
Gym/Fitness centre	144	1.9%	182	1.9%	190	1.9%	264	1.6%	183%
Residential home	110	1.5%	178	1.8%	189	1.9%	370	2.3%	336%
Public bath/pool	112	1.5%	137	1.4%	125	1.3%	178	1.1%	159%
Other vehicle (excl. train, bus, tram, ferry, taxi & ambulance)	114	1.5%	135	1.4%	142	1.4%	194	1.2%	170%
Shopping mall	112	1.5%	129	1.3%	117	1.2%	202	1.3%	180%
Golf course	95	1.3%	109	1.1%	74	0.7%	140	0.9%	147%
Station/terminal (train, bus, tram, ferry, taxi)	53	0.7%	89	0.9%	76	0.8%	79	0.5%	149%
Nursing home	41	0.6%	73	0.7%	75	0.8%	166	1.0%	405%
Amusement park	49	0.7%	55	0.6%	47	0.5%	87	0.5%	178%
Outdoors (street, square, park)	27	0.4%	49	0.5%	58	0.6%	111	0.7%	411%
Airport	37	0.5%	52	0.5%	44	0.4%	74	0.5%	200%
Public beach	32	0.4%	44	0.4%	52	0.5%	75	0.5%	234%
Hospital, geriatric ward	22	0.3%	24	0.2%	43	0.4%	64	0.4%	291%
Train, bus, tram, ferry, taxi (not in station/terminal)	36	0.5%	33	0.3%	36	0.4%	46	0.3%	128%
TOTAL	7408	100%	9834	100%	9945	100%	16120	100%	218%

Legend: *Table 7 shows the number of AED per location as stated in SAEDREG per year over a four-year period and the total increase over the four-year period 2013 – 2016.*

Survey of AED owners in a Swedish region

A total of 218 AEDs was identified in the Gotland region. Amongst those AEDS, 57% (n=124) were registered in SAEDREG and 43% (n=94) were non-registered. The most common location of registered as well as non-registered AEDs was offices and workplaces, at 30% vs. 27% respectively, followed by shops at 15% vs 14% respectively (table 8). When including the non-registered AEDs to the SAEDREG registered AEDs, the number of AEDs/10,000 inhabitants on Gotland increased from 2.5 to 4.4

Table 8. *Region Gotland, SAEDREG registered versus non-registered AEDs 2017*

	SAEDREG-registered AEDs **n=124**	**Non-registered AEDs** **n=94**	**P value**
Registered AEDs = Yes (%)	124 (100.0)	0 (NA)	
Location (%)			<0.001[1]
Shop/boutique	19 (15.3)	13 (13.8)	
Other vehicle	0 (0.0)	4 (4.3)	
Office / workplace	37 (29.8)	2 (26.6)	
Public beach	2 (1.6)	0 (0.0)	
Airport	2 (1.6)	0 (0.0)	
Golf club	1 (0.8)	0 (0.0)	
Gym	1 (0.8)	3 (3.2)	
Residential home	2 (1.6)	3 (3.2)	
Hotel / hostel	3 (2.4)	1 (1.1)	
Sporting facility	4 (3.2)	8 (8.5)	
Church	6 (4.8)	0 (0.0)	
Amusement park	0 (0.0)	2 (2.1)	
Public house	11 (8.9)	14 (14.9)	

Swimming facility / pool	3 (2.4)	0 (0.0)	
Hospital	3 (2.4)	0 (0.0)	
School	5 (4.0)	4 (4.3)	
Train/bus/boat	0 (0.0)	4 (4.3)	
Outdoor street/square/park	2 (1.6)	6 (6.4)	
Health centre/private clinic/dentist	10 (8.1)	1 (1.1)	
Nursing home	12 (9.7)	3 (3.2)	
Other	1 (0.8)	3 (3.2)	
Awareness of SAEDREG? **No/Yes (%)**	0/0 (NA/NA)	**70/24 (74.5/25.5)**	
Reason for not registering? (%)			NA
Does not want it to be visible	0 (NA)	3 (12.5)	
Does not want to be dispatched by EMDC	0 (NA)	1 (4.2)	
Hard to register	0 (NA)	6 (25.0)	
Other	0 (NA)	13 (54.2)	
Risk of theft	0 (NA)	1/94 (4.2)	
How was the AED acquired (%)			<0.001[2]
Company	85 (71.4)	90 (95.7)	
Gift	3 (2.5)	4 (4.3)	
Internet	2 (1.7)	0 (0.0)	
Other	29 (24.4)	0 (0.0)	
Data on functionality			

Self-test passed = Yes (%)	102 (100.0)	92 (100.0)	
Battery ok = No/Yes (%)	0/119 (0.0/100.0)	4/90 (4.3/95.7)	0.0366[2]
Electrodes ok = No/Yes (%)	23/95 (19.5/80.5)	23/70 (24.7/75.3)	0.4549[1]
Guidelines updated = No/Yes (%)	21/29 (42.0/58.0)	1/81 (1.2/98.8)	<0.0001[2]
CPR training = No/Yes (%)	19/98 (16.2/83.8)	31/60 (34.1/65.9)	0.0048[1]
Local alarm plan = No/Yes (%)	79/34 (69.9/30.1)	64/27 (70.3/29.7)	1.000[1]

Legend: *Table 8 shows the results of a survey carried out in the region of Gotland, Sweden in 2017.*
Abbreviations: *AED – Automated External Defibrillator, NA – Not available, SAEDREG – Swedish AED registry, EMDC – Emergency dispatch centre.*
[1]*Pearsons* X^2 *test.* [2]*Fishers exact test.*

According to the survey, the overall functionality of AEDs was good in all 218 AEDs whether they were registered in SAEDREG or not. In the nonregistered group, however, four AEDs had a dead battery and would not have been able to deliver a shock if needed.

The fact that the AED owner was unaware of SAEDREG was the main reason for them not registering their AEDs. In the cases where the owner knew of the AED register, the registration process was mentioned as a barrier to registration.

6 DISCUSSION

The main findings for the separate studies included in this thesis are listed below.

- Despite a tool that display AED locations on dispatcher's maps, AED accessibility coupled with callers being alone on scene when calling 112 (emergency services) were the two main barriers to AED referral by dispatchers.

- When using an objective geographical classification of urban areas in Stockholm to analyse AED locations and public OHCA incidence we found that the majority of public OHCA occurred in areas categorised as residential where AED availability was limited.

- Drones/UAV are feasible to use for transport and delivery of AEDs, with the greatest effect in regard to arriving prior to ambulance occurring in rural areas. The most practical way to deliver the AED would be to either land it close to the location of collapse or to drop the AED from an altitude of 3-4 metres to a receiving bystander.

- The number of AEDs in the Swedish AED registry doubled from 2013 to 2016, and the most common locations for AEDs are in workplaces/office locations where 45% of them are placed. SAEDREG, however, does not include all AEDs. According to our survey of 218 AED owners in the Swedish region of Gotland, 94 AEDs were not registered in SAEDREG. Additionally, the survey found that in 74.5% of the 94 un-registered AEDs the owner was unaware of the existence of the Swedish AED registry. Most unregistered AEDs in this survey were not registered for that reason. The second most common cause of not registering AEDs in SAEDREG was the perceived difficulty of the registration process.

- Overall AED functionality in this region was good, but of the 94 AEDs not registered in SAEDREG n=4 had a dead battery.

6.1 WHAT IS THE POTENTIAL FOR IMPROVING CURRENT AED LOCATIONS?

The positive effect of AEDs on increased survival in OHCA is undisputed; however, the actual use of AEDs is low.

In a study from the United Kingdom, Deakin et al. (2014) reported that in 1,035 confirmed OHCA an AED was successfully brought to the location in 4.25%. In Japan, Kitamura et al. (2010) reported shock by an AED in 3.7% of such cases and in the United States in a material of 13,760 OHCA, Weisfeldt et al. (2010) reported only 2.1% having an AED applied.[27 94 130]

With increasing numbers of AEDs in Sweden, a two-fold increase of AEDs in the Swedish AED registry (SAEDREG) from 2013 – 2016[12] (Fredman, study 4 - unpublished), the proportion of public AED use increased only marginally.[102]

So, by merely increasing the numbers of AEDs in society the intended increase in survival has yet to come. Furthermore, placing large amounts of AEDs in society is very costly and does not have a significant impact on OHCA survival if it is not managed properly and supported by preceding public awareness campaigns.[118 159]

Even with significant state-wide or nationwide Public Access Defibrillation (PAD) interventions it seems challenging to increase the rate of public AED use.[97]

In the case of an OHCA, AED use is highly dependent not only on the actual numbers and specific locations of AEDs but also on public awareness and to a certain degree, on bystanders' willingness to act. So, in order to improve current AED locations, I believe we should put the effort in awareness campaigns to make already made investments to better use.

An AED will never save a life if no one knows where to find it and how to use it.

6.2 THE ROLE OF THE DISPATCHER

The first link in the chain of survival is perhaps the most important; everything starts there. Delays in this area may be irreparable.

The call taker at the dispatch centre plays an important role in the "first resuscitation team", supporting the caller in providing high quality, uninterrupted CPR. In the current guidelines from ERC, it is also suggested that dispatchers guide callers to nearby AEDs to increase AED use.[126]

When provided with an application that displays AED locations from SAEDREG on their maps along with instructions of how and when to use it, dispatchers at four Swedish dispatch centres referred callers to nearby AEDs in only two cases.[72]

The distance to nearby AEDs from the location of the suspected OHCA victim proved to be the biggest barrier to successful AED referral and use. Only 200 of the 3,009 calls concerning suspected OHCA received at dispatch centres occurred within 100m of an AED.

The 100-metre distance was selected based on the suggestion by Aufderheide et al. (2006) that a bystander could retrieve an AED within 1.5 minutes thus leading to defibrillation within 3 minutes.[125] It is reasonable to believe that many motivated bystanders could outperform this time/distance. Longer distances are currently used for alerting volunteer lifesavers using mobile phone applications.[135 160-162] A study referring volunteers to nearby AEDs in simulated emergency calls in a shopping mall to use on mannequins showed a decreased time to first simulated shock saw a significant reduction in time if instructions on AED location were given to the "caller". Here the maximum distance to AED was 200 meters.[163]

It has been stated that AED accessibility poses a problem for potential AED use.[138 164] Within our data set, in only 76 of the 200 cases of suspected OHCA ≤100m from an AED the AED was available for use at the time of call.[72]

We listened to the audio files of the 200 emergency calls of suspected OHCA ≤100m from an AED to identify the reasons call takers at the dispatch centre did not refer callers to nearby AEDs. It is very important to note that we analysed audio tapes of cases of suspected OHCA, not "verified" OHCA as treated by ambulance and registered to SCAR, the common data source for analysing OHCA outcome. This is why "signs of life" as well as "signs of death" are listed as reasons for both not referring callers to AEDs and for advising telephone assisted CPR (T-CPR). This approach in analysis may give a truer picture of the actions in the early stages of an emergency call and could prove valuable in future research on these topics.

Somewhat disappointingly, we were in the majority of cases unable to identify a definite reason for lack of AED referral. As a result, the most common reason for not referring callers to nearby AEDs was deemed, "no obvious reason".

However, in accordance with previous findings that analysed dispatcher interaction with callers in OHCA situations[73] we identified that the caller not being directly at the patient's side as a leading cause for dispatchers not referring callers to nearby AEDs.[72]

The emergency call situation is stressful enough as it is. The top priorities for the call taker in such circumstances are to recognise the cardiac arrest at an early stage, retrieve the location of the OHCA, and initiate T-CPR. Whilst a second dispatcher deploys the ambulance to the location, the call taker should remember to refer the caller to an AED during ongoing telephone assisted CPR and to activate an extra layer in the maps to look for available nearby AEDs.

An Australian study describes a system of AEDs being reported to the computer aided dispatch system that identifies OHCA calls from AED equipped locations so the call-taker can inform the caller.[165] However, the rate of AED referral is not reported by the authors.

If the role of the dispatcher to refer callers to nearby AEDs as suggested by ERC[126] shall have an impact on AED use, the dispatcher must be supported by a system with automated reminders, like a "pop-up" window, that identifies, select and display nearby accessible AEDs when the call concerns a suspected OHCA.

6.3 WHERE SHOULD AEDS BE INSTALLED?

The European Resuscitation Council (ERC) suggests placing AEDs in, "locations with many visitors and in densely populated areas." It specifically points out seven location types for AED installation locations: airports, railway stations, bus terminals, sport facilities, shopping malls, offices and casinos.[126]

These clear guidelines and the specific nature of the suggested locations make it highly unlikely that I ever will visit an airport or a casino without at least one available AED.

But perhaps we're missing something here.

The suggested locations in the international guidelines derive from landmark studies like Valenzuela et al. (2000) that reports a 70% survival rate in witnessed collapses in casinos in Nevada as well as an article by Caffrey et al. (2002) that studied AED use in airports in Chicago.[92 93]

An airport is an easy location to identify because of its unique structural qualities. The same can be said for shopping malls, casinos etcetera.

If historic OHCA incidence locations are used as guidance for AED installation but researchers primarily focus on easily distinguishable locations such as airports or casinos that have clear boundaries with adjacent areas and distinct ownership, we're prone to miss out on the positive effects of PAD for the majority of OHCA victims, those in residential areas, and surviving a OHCA have been described as a postcode lottery.[166]

In *study 2* in this thesis, we analysed public OHCA incident locations and AED installation locations in Stockholm and used a data set of objective classified land use to distinguish between residential and non-residential areas based on the respective areas' dominant land use and cover. This analysis revealed that 47% of public OHCA occurred in areas classified as residential areas. Areas that contained only 29% of the available AEDs.[119]

According, however, to SAEDREG, the AED locations in Sweden follow the ERC guidelines well with 45% of the more than 16,000 AEDs located in offices.[12]

This method of using Urban Atlas as in *study 2* is not primarily designed for calculation of population density[119], but the results indicate that AEDs in Stockholm are not located in "densely populated areas", i.e. residential areas. In order to suggest locations for AED installation we need to look not only on where OHCA occur but also look for blank spots on our AED maps.

6.4 LOCATION OF OHCA AND SUGGESTIONS FOR AED INSTALLATION

The ERC guidelines suggest placing AEDs in, "locations with many visitors and in densely populated areas"[126] thus including residential areas.

The guidelines, however, do not reflect further upon how to identify and distinguish these locations (number of inhabitants/km2? night-time vs daytime inhabitants? number of visitors over time? or population annually?). As a result, this important task is left to the decision makers in a city or region or the AED owner, this may be one of the reasons AEDs are absent in residential areas.

Even though the majority of OHCA occur in patients' homes, placing AEDs in those environments has proven not to be an efficient solution to increasing survival in OHCA in residential settings.[167] Placing AEDs in residential areas, however, outside of homes may prove valuable.[42 119]

Methods are emerging for covering residential areas in a structured manner with the assistance of a network of volunteer lifesavers alerted with instructions to perform CPR and guided to AEDs.[135 147 161] Cabinets for safe and heated AED storage are available and can facilitate AED placement in residential areas, however these are not yet common in Sweden.

Even after several attempts to identify high-risk locations of OHCA[42 89 90 103 105-123] and numerous studies to identify beneficial locations for AED installation that look at retrospective OHCA incidence[90 117 133], mathematical models[111], demographic characteristics[42] and geographic information systems (GIS)[104], the most suitable location to install AEDs still evades researchers.

In a study from Paris, France Marijon et al. (2015) analysed public OHCA incidence and found it poorly associated with population density on one hand but on the other hand closely associated with population movement.[168]

In a city or suburb with several blocks of buildings that all contain many apartments and either share a common owner or are each privately owned, the responsibility of AED installation and maintenance may be tricky. Also in urban areas with high-rise buildings, the vertical distance for AED accessibility must be included in the calculation.[169 170]

In sparsely populated areas, the incidence of OHCA is low and with long distances for dispatched ambulances, survival is generally low even when supported by dual-dispatch of firefighters.[171] In such areas compensating systems may have a place. We evaluated an Unmanned Aerial Vehicle (UAV)/drone system for transporting AEDs to remote locations and identified 10 locations for installation based on retrospective OHCA data in rural areas. The calculation revealed a mean reduction of 19 minutes to AED arrival and through test flights, we found it safe and feasible to land and deploy AEDs to bystanders on the ground.[139]

This is a type of system with a great potential. Similar studies using data models show reduced time to AED delivery on scene.[140 141] Perhaps AEDs will not be the only things delivered. Anything rather lightweight that requires time sensitive delivery could be transported by drone.

To suggest locations for AED installation is evidently no simple task, but I believe a structured approach can help. The ERC need to address the population density issue to aid decision making entities and maybe also suggest population movement as a measure to calculate OHCA risk.

Transportation of AEDs from where they are located to where they are needed has proven valuable.[135] Regardless of if the AED is delivered by a dual-dispatched team of firefighters, volunteer lifesavers alerted through smartphone solutions or brought to the scene using a drone system this gives every device a larger area of action, and this the actual location a little less important.

6.5 WHAT IS HIDDEN IN THE “OTHER” LOCATIONS?

In many of the studies supporting the idea of PAD and AED use in public, the incidence locations for OHCA are identified to a certain level and the effects are based on OHCA incidence in easily distinguished locations as casinos and airports.[131]

The largest group of OHCA cases, however, are often defined as occurring in “other” locations, are left out of the analysis and are not revisited. The analysis of OHCA locations in the renown PAD trial by Hallstrom et al. (2004) is merely found in a conference paper. It has not been published.[172]

A large study reporting OHCA outcome in public locations in Japan documents a high use of AEDs in railway stations (41%) and sport facilities (56%) although the actual numbers of OHCA cases reported in those locations were quite low, n=17 and n=23 respectively. However, n=562 of the OHCA cases (68%) occurred in “other” locations. These cases were not analysed further, and AED use in those instances was low, at only 3.6%.[131]

So, if an OHCA is reported by ambulance to have occurred at an easily distinguishable location such as a train station or an airport and an AED is used, that incident strengthens the guidelines’ recommendation of AED installation in such sites.

But what if the OHCA occurs on a street in a busy commercial district or in a public park in the centre of town where the boundaries and ownership of those locations are not that easy to distinguish? Or what if the OHCA occurs in a small convenient store just around the corner from that busy street?

What will the ambulance crew that respond to an OHCA there state as the location? Street? Store? Other location? And how will this location be interpreted by researchers or healthcare officials following up on incidence locations for OHCA?

In a EuReCa study that covers 27 European countries, location of collapse is only reported as public vs residential location.[9] Furthermore, the EuReCa-ONE study protocol suggests fewer location types than the Utstein template and only covers five "public" locations and, of course, the ubiquitous "other".[173]

In Sweden the second most common location for public OHCA after home, is street/square where 7.2% of all OHCA occur.[12] Simply analysing these cases as a uniform group are likely to be subject to multiple biases. The cases of OHCA stated by ambulance crews to have occurred in the location classified as "street" according to the Utstein resuscitation registry template may have great variance.

A "street" location may differ significantly, from a small suburban road to a busy parking lot outside a shopping mall. The variance in location may be associated with the same outcome differences between OHCA in public location and home environment.[27 40 42 43]

A more objective analysis of location for OHCA incidence would give a truer analysis of incidence and outcome. Urban Atlas, the freely available data set of objective classification of land use used in *study 2*, can assist in providing comparative data for most urban areas in the European Union.[119 154 155 152]

6.6 IS AED OWNERSHIP A CONCERN FOR AED INSTALLATION?

All the seven types of locations specifically suggested by ERC for AED installation [126] covers a definite area, each easily distinguishable from adjacent areas. Also, most of them have a very defined ownership and often a security and maintenance organisation tied to them. Additionally, they are associated with generous access hours. All of these are important characteristics in enabling a successful PAD programme.[97]

Who, however, own a "densely populated area"?
Often many entities own these areas; sometimes maybe none do. A city square is perhaps owned by the city itself, but the busy merchant street hosts several owners, some of small businesses, some of multinational franchising chains, some of private homes.

A study from Canada analysed OHCA incidence location and business locations. It covered them both in terms of geography and accessibility (spatiotemporal coverage). The study also identified bank machines and coffee shops suitable for AED installation and proposed a partnership collaboration for PAD programs.[114] This is an appealing approach to AED proliferation because these locations are well known, both to visitors and inhabitants. With a collaborative approach, perhaps ownership and maintenance issues can be resolved more easily.

The ownership concern around AED installation in public locations, specifically those locations in a "densely populated area", must be addressed given that the benefits of PAD are not only dependent on AED installation but on AED availability, logistics to facilitate use and information regarding their whereabouts and use being distributed to the community as well.[97 138 102]

In *study 4,* in the select region of Gotland, Sweden, we conducted a survey to AED owners and found that AED functionality was high regardless of whether the AED was registered in the Swedish AED registry or not. The AEDs that had a dead battery were all in the non-registered group. Every six months the AED owners in SAEDREG receive an email telling them to verify the location and accessibility of the AED and also to check the battery and electrodes.

This kind of follow up on AED functionality is vital for potential AED use and should be encouraged. The follow up can be part of a structured PAD programme, the validation process in a national AED registry or as part of a customer relations programme from AED retailers. It could also be done just as effectively by setting a calendar alarm on one's cell phone on specific dates annually to check the status of one's AED.

Ultimately, a completed AED functionality check is more important than how one makes sure it is completed.

6.7 SUGGESTIONS FOR AED INSTALLATION, WHAT IS NEEDED?

The historic locations of OHCA have been the primary source for guidance in suggesting AED installation locations.[89 90 117 118 121 122 133]

Not only is the Utstein resuscitation registry template based reporting system where the ambulance that responds to the cardiac arrest records the type of location of the arrest needed, the exact geographic location of OHCA incidence is valuable and makes geographical analysis possible. The dispatch centre that dispatches ambulances often has these coordinates and could use them to fertilize a national cardiac arrest registry.

The locations of already installed AEDs is important for suggesting new locations for AED installation. By analysing them it is possible to avoid clustering of AEDs and to promote AED installation in "blank spots" in society. Setting up a national AED registry that gathers the geographic locations of AEDs as precisely as possible provides both this possibility and the possibility to perform regional comparisons in AED distribution and follow up.

Because ERC suggests AEDs be installed in densely populated areas[126] the parameters of such areas must be known. A database of population density preferable with demographic data makes it possible to calculate the population at risk and can be an important piece in the puzzle to suggest AED installation.

A national resuscitation council or other entity that can create awareness and increase bystander willingness to act is important because no AED has ever saved a life without being actively used by someone. Someone with the skill and courage to act is usually the product of education and training.

6.7.1 GIS methods for generalizability

In many of the papers referenced in this thesis, Geographic Information Systems (GIS) is used for analysing OHCA incidence locations and/or AED locations.

These studies, however, somewhat differ from other research literature in the field due to the fact that reproduction of the findings seldom is performed.

Two papers from 2009 and 2010 by Folke et al. used a 100m x 100m grid cells from something called the European Grid System to propose strategic implementation of AEDs and determine differences between OHCA incidence location in residential or public locations.[42 118] From what I can find, these two publications are the only two ones to use this grid cell system, so the generalisability of the method is unknown.

This is just one example of how infrequently seemingly good methods for analysing geographic relations of OHCA and AED locations are used and findings are not reproduced.

In a study by Sasson et al. (2012), three different GIS methods were used to analyse clustered hot spots of OHCA incidence. The researchers justified this by asserting that instead of a single acceptable method, each of the three methods have different advantages and disadvantages and the results overlap between them.[105]

In many papers on AED installation or OHCA incidence, cutting edge GIS methods are used but reproduction of results is scarce. If results cannot be reproduced, are they reliable?

When using GIS to analyse geographic relations between for example OHCA incidence and AED locations the data input is very important. It is crucial to have coordinates for both types of locations. With different methods being used, the results will likely differ, making comparability and generalisability elusive.

In *study 2* we used ready available GIS methods in a freely available open source Q-GIS software for analysis of geographic relations between OHCA and AED locations. But we also used a generalised data set of land cover and -use created by European commission´s global monitoring of environment and security.

I propose that ERC or ILCOR include geographic data (coordinates of locations) for OHCA incidence in the Utstein template to promote comparable analysis between regions. This also opens up for precise classification of OHCA incident locations. And I suggest use of standardised GIS methods to increase generalisability in geographical analysis of OHCA incidence.

6.8 BARRIERS TO OVERCOME TO IMPROVE AED USE

6.8.1 AED Accessibility

In Sweden the most common location for AED installation is offices; where 45% of all AEDs in SAEDREG are installed.[12] AEDs being installed in locations with limited access such as an office leads to AED inaccessibility during times associated with increased OHCA incidence, like nights and weekends.[138]

Placing AEDs in locations with more favourable access hours can improve AED accessibility.[114] Collaborating with the community to place AEDs in 24-hour access locations could also improve general awareness of OHCA and AED use.

When an AED is installed, whether in a public location or a residential area, its location needs to be made known otherwise it is unlikely that a witness of an OHCA will find and use the AED. ILCOR has designed an AED sign for world-wide recognition of AEDs and recommends its use to facilitate location and use of AEDs as quickly as possible.

Figure 12.. *Based on the ILCOR standard The Swedish Resuscitation Council created a graphic profile for AED signage and distributed it widely to AED vendors, CPR educators and potential AED users in Sweden.*

Published with permission from the Swedish resuscitation council.

AED installation in residential areas is scarce, even though 60-80% of all OHCA cases occur there.[39 40] We also saw that the majority of OHCA in public locations occur in residential areas.[72]

AEDs placed in outdoor cabinets in residential areas could improve AED accessibility and possibly improve AED use. Always choose the location with the best accessibility for AED installation, preferably 24h/7/365 to improve each devices hours of action.

6.8.2 Bystander awareness

Bystander awareness and willingness to act is a key not only to improved CPR rates but to improved AED use. Civilian response systems like those used in Holland and Sweden to alert volunteer lifesavers through their cell phone and guide them to OHCA victims and nearby AEDs can improve CPR rates and AED use.[135 147 161]

Relying on dispatchers to refer callers to nearby AED is possible but needs technical support to have a great impact.[72]

CPR training courses are crucial to overcome barriers for AED use.[126] During the course the AED is presented by the instructor and participants can see and try the device in a safe and pedagogical environment and put it into the context of performing CPR in a prehospital context. These courses are also a good platform for informing about national AED registries and local awareness campaigns.

6.8.3 AED functionality

An AED must be fully functional at all times to be able to deliver a lifesaving shock. The number of AEDs spread throughout the world has been increasing at a tremendous rate, but the lifespan of each device is unclear.

How many of the AEDs sold in 2008 are still around and functional by 2018? Do batteries and electrodes remain ok for that long?

An AED needs to be regularly maintained to remain operational and reminders can be sent from a national AED registry (Fredman, study 4 – Unpublished). Perhaps a one-way approach is insufficient, reminders should also be done through AED retailers or dispatch centre officials for example.

7 METHODOLOGICAL CONSIDERATIONS

Study 1

In the analysis, we included calls concerning suspected OHCA cases as we wished to analyse the true proportion of cases where the dispatcher should refer callers to AEDs based on the first identification of emergency.

We believe this gives us a truer understanding of the volumes of cases where AED referral should be carried out. If analysis would be carried out in patient material provided from SRCR all cases with “signs of life” and “signs of death” stated as reasons for not referring an AED.

A greater distance for selecting “nearby” AEDs could have used, the 100m distance is most likely to narrow. Such narrow geographical limitations should be generally avoided and perhaps should always the three “nearest” AEDs wold be suggested to dispatchers for referral, regardless of distance.

Study 2

The use of Urban Atlas opens up for comparing and generalizing results between European cities, regions or countries. But until this is done we cannot say much about if this actually is an effective method, but it is appealing that the data set is freely available for over 300 cities/regions. Also, with Urban Atlas it is not possible to account for population density since the geographic areas are not interrelated with census tracts.

Study 3

The GIS model is only a model, with more tests, weighed different, the results would differ, infinite. A more fine-tuned selection of OHCA cases focusing on witnessed/non-witnessed and different age categories or OHCA incidence locations could also lead to different results. We are aware of this but stuck to our plan of methodology.

To fully test the plausibility of drones delivering AEDs more test flights need to be carried out. But we were limited in time and resources and also the fact that legislation does not permit autonomous flights with drones out of sight. So, further testing of actual time reduction would have been hampered due to the fact that the UAV pilot must have eyes on it from a car.

Study 4

Our analyses relied on four years of data, 2013 – 2016, even though the SAEDREG has been active since 2009. The reason for this is that AED data from the first years were converted from one database structure and fully digitalised in late 2012 so annual comparisons previous to 2013 is not possible. The formatting of how AED owners enter hours of availability in SAEDREG made comparison of AED accessibility virtually impossible so it was left out in the analysis.

We choose the region of Gotland for survey since it is well defined being a small island. It is Sweden’s smallest region and the size may limit the generalizability but on the other hand it made the survey process manageable and we believe we came close to cover 100% of the AEDs in the region, but we cannot be sure.

8 CONCLUSIONS

8.1 OVERALL CONCLUSION

AEDs are infrequently used, with better location and increased accessibility this could change, and perhaps it is more important to push for 24 hour-AED-accessibility than to identify optimal location with limited accessibility.

There is a mismatch between where OHCA occur and where AEDs are located. The suggested locations for AED installation are missing residential areas, where the majority of OHCA occur, even OHCA in public is common in residential locations.

New methods for transporting AED like Drones have the potential to compensate for prolonged ambulance response time, especially in rural areas.

Dispatch centres have the potential to increase AED use at an early stage in OHCA but if we are to rely on call takers or dispatchers to refer callers to nearby AEDs the numbers of AEDs and their accessibility must increase important. Moreover, the decision and selection of AEDs for referral must be automated. The dispatchers are too busy to remember this otherwise.

There will always be need for an increase in general awareness for AEDs and OHCA and a national AED register play an important role not only by displaying AED locations to citizens to increase awareness but for dispatchers to refer callers and also in reminding AED owners to keep their AEDs operational and to maintain their lifesaving capability.

9 FUTURE PERSPECTIVES

AEDs are predicted to decrease in cost and increase in number and AED installation should be structured and continuously monitored within the frame of PAD-programs and based on both retrospective data as well as real-time crowd flow analysis to compensate for the current low AED use.

The accessibility of each AED needs to improve and should aim for 24-hour availability, seven days a week, 365 days a year and it is feasible with regards to the current technology available in heated and lockable cabinets.

Emerging technology using mobile positioning and alerting of volunteers to OHCA facilitates early CPR and early defibrillation by increasing each AEDs radius of action may be an option for improving AED use for both public and residential areas.

Using unmanned aerial vehicles, i.e. drone technology to move AEDs over great distances is potentially possible and may serve as a complement to EMS in rural, semi-rural or semi-urban environments.

A more precise and objective categorisation of OHCA incidence locations is needed in order to better place AEDs where OHCA occur. An approach focusing on reproducing and generalising previous findings of studies analysing OHCA incidence and AED locations could provide valuable information and lead to the use of standardised methods for GIS analyses of OHCA and AED locations.

It is time to put systems together and benefit from the combination and coordination of national AED registries, dispatch centres referral of AEDs, volunteer lifesaver activation and possibly drones transporting AEDs.

10 SUMMARY IN SWEDISH

Hjärtstopp utanför sjukhus är en ledande dödsorsak i många västländer. Det läggs ner mycket resurser och ansträngningar på åtgärder för att förbättra överlevnaden. Tidig hjärt-lungräddning (HLR) och användning av hjärtstartare (AED) ökar chansen för överlevnad avsevärt. År 2016 rapporterades 5 312 fall av hjärtstopp utanför sjukhus till svenska HLR registret men endast 577 (11%) överlevde. Andelen hjärtstopp som får HLR innan ambulansen anländer är hög i Sverige (73%) och antalet hjärtstartare i samhället ökar snabbt men användningen är låg. Om användningen av hjärtstartare kan öka, kan fler patienter räddas.

Syftet med denna avhandling var att i fyra separata studier undersöka hur logistik och placering av hjärtstartare kan leda till tidig defibrillering.

Metod och resultat

Studie 1 var en prospektiv studie vid fem larmcentraler i Sverige där larmoperatörerna fick tillgång till det Sveriges hjärtstartarregister och fick instruktioner i att hänvisa den som ringde 112 till närmaste hjärtstartare då ärendet rörde misstänkta hjärtstopp. Av 3009 112-samtal om misstänkta hjärtstopp under sju månader inträffade endast 200 inom 100m från en hjärtstartare och i endast två fall hänvisade larmoperatören till en hjärtstartare. Hjärtstartarnas tillgänglighet, dvs öppettiderna och det faktum att de som ringde ofta var ensamma på platsen identifierades som hinder för denna metod för att öka användningen av hjärtstartare.

Studie 2 var en retrospektiv analys av var i Stockholms län hjärtstartare placerats i förhållande till var hjärtstopp inträffat på offentliga platser. Vi använde geografiska informationssystem (GIS) och ett fritt tillgänglig dataset för markanvändning (Urban Atlas) för analysen. Det var stora skillnader i hur hjärtstartare placerats. Trots att incidensen av hjärtstopp på offentliga platser i "bostadsområden" liknade den i "icke-bostadsområden" var tillgången på hjärtstartare signifikant högre i "bostadsområden".

Studie 3 var en explorativ studie för att undersöka möjligheten att använda drönare för att transportera hjärtstartare för att minska tiden för defibrillering. Studien omfattade testflygningar av ett drönarsystem utrustat med AED samt en retrospektiv GIS-analys av lämpliga platser för installation av drönare utrustade med AED för maximal täckning av hjärtstopp i Stockholms län. Metoden visade att på detta sätt skulle en hjärtstartare kunna komma på plats i medel 19 minuter tidigare än på traditionellt vis.

Studie 4 är en översikt över det svenska hjärtstartarregistret och visar en dubblering av antalet registrerade hjärtstartare i Sverige sedan 2013 och att majoriteten (45%) av 15 849 hjärtstartare placeras på kontor/arbetsplatser. I en utvald region i Sverige hittades ytterligare 94 hjärtstartare som inte registretars i Sveriges hjärtstartarregister vid en genomgång av kundregister från AED-leverantörer och en enkät riktades till innehavarna av alla 218 hjärtstartare med fokus på apparatens funktionalitet och i förekommande fall anledningen att den inte registrerats i hjärtstartarregistret.

AED-funktionaliteten var hög i båda grupperna och ägarna uppgav krånglig registreringsprocess som huvudanledning för att inte registrera apparaten i Sveriges hjärtstartarregister men majoriteten kände heller inte till Sveriges Hjärtstartarregister.

Slutsatser

Att larmoperatören hänvisar inringare till är en framkomlig väg för att öka användningen av hjärtstartare men utbildning och tekniskt stöd för larmoperatörerna måste implementeras om det skall ha någon verklig effekt.

Hjärtstartare placeras inte där hjärtstopp inträffar. De flesta hjärtstartare i Sveriges hjärtstartarregister är placerade i kontor/på arbetsplatser. Men majoriteten av hjärtstoppen utanför sjukhus som inträffar på allmän plats inträffade i bostadsområden där endast en tredjedel av hjärtstartarna placerats.

Att transportera hjärtstartare med drönare är möjligt och skulle kunna leda till kortare tid tills första möjliga defibrillering.

Ett nationellt hjärtstartarregister av god kvalitet är viktigt för att öka medvetenheten om hjärtstartare i samhället, men långt ifrån alla hjärtstartare i Sverige är registrerade i Sveriges hjärtstartarregister och många försvinner i valideringsprocessen. Funktionaliteten på apparaterna är god men påminnelser om att kontroller batterier och elektroder är viktigt för att bibehålla den goda funktionaliteten.

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