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OUT OF HOSPITAL CARDIAC ARREST

With focus on Bystander CPR and Public Access Defibrillation

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With Focus on Bystander CPR and Public Access Defibrillation

THESIS FOR DOCTORAL DEGREE (Ph.D.)

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Till Annika, Casper & Hugo

ABSTRACT

Background

Out-of-hospital cardiac arrest (OHCA) annually affecting hundreds of thousands of patients in Europe alone. Survival is highly dependent on time to treatment (cardiopulmonary resuscitation (CPR) and defibrillation). Long emergency medical system (EMS) time intervals and low bystander CPR rates are major obstacles for increased survival. New treatment strategies are needed to reach and treat patients faster. Automated external defibrillators (AEDs) make it is possible for lay people to deliver life-saving shocks within minutes, a concept known as public access defibrillation (PAD). Further, the development of mobile phone technology makes it possible to identify and recruit lay volunteers to nearby OHCAs for life-saving actions.

Aim

To evaluate the new treatment possibilities of PAD and mobile phone technology involving lay and non-health care responders for early CPR and defibrillation in case of OHCA

Methods

In all studies, data from the Swedish Cardiac Arrest Register (SCAR) were used. This is a national register of data from resuscitation attempts from EMS treated OHCAs since 1992. In *Study I* SCAR data was analysed in connection with the numbers of cases and changes of characteristics over time (1992-2005) among OHCAs patients suffering arrest outside home. In *Study III,* SCAR data and records from ambulance police and fire services was reviewed to evaluate the impact on survival of different defibrillation strategies: police and fire services (first responders), EMS or PAD in OHCAs in public locations. In *Studies II* and *IV* a mobile positioning system (MPS) was used to geographically locate and dispatch CPR-trained lay volunteers to nearby OHCAs. *Study II* was a pilot study in Stockholm city centre and *Study IV* was a full-scale countywide randomized controlled trial.

Results

In *Study I*, 26% of all OHCAs were found to be potential subjects of PAD. Among these cases, the proportion of patients with an initial rhythm that could be defibrillated decreased over time, but overall survival increased. *In Study II*, 1200 lay volunteers were recruited. During six months there were 92 cases of suspected OHCAs where the MPS was triggered. In 45% of these, one or more lay volunteer(s) reached the scene prior to the EMS. In *Study III*, 474 of 6532 OHCAs were defined as subjects for PAD and were defibrillated at a public location. Survival was 71% (n=51) in patients defibrillated by a public AED versus 31% (n=101) in patients defibrillated by the EMS (p<0,001). In cases defibrillated by first responders survival was 42% (n=22). In *Study IV,* 5989 lay volunteers were recruited. 667 cases of EMS-treated OHCAs where the MPS was triggered were analysed. In cases randomized to activation of the MPS for dispatch of lay responders bystander CPR rate was 62% versus 48% where the system was not activated (absolute difference, 13.9 percentage points; 95% CI, 6.2 to 21.2, p <0.001).

LIST OF ORIGINAL PUBLICATIONS

I. Ringh M, Herlitz J, Hollenberg J, Rosenqvist M, Svensson L.
Out of hospital cardiac arrest outside home in Sweden, change in characteristics, outcome and availability for public access defibrillation.
Scand J Trauma Resusc Emerg Med. 2009 Apr 17;17:18.

II. Ringh M, Fredman D, Nordberg P, Stark T, Hollenberg J.
Mobile phone technology identifies and recruits trained citizens to perform CPR on out-of-hospital cardiac arrest victims prior to ambulance arrival.
Resuscitation. 2011 Dec 82(12):1514-8.

III. Ringh M, Hollenberg J, Nordberg P, Jonsson M, Rosenqvist M, Svensson L.
Survival after Public Access Defibrillation in Stockholm, Sweden.

IV. Ringh M, Rosenqvist M, Hollenberg J, Fredman D, Nordberg P, Jonsson M, Järnbert-Petterson H, Svensson L.
Impact on Bystander Cardiopulmonary Resuscitation of a Mobile Phone Positioning System and Dispatch of Lay Volunteers to Out of Hospital Cardiac Arrests. A Randomized Controlled Trial.

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LIST OF ABBREVIATIONS

AED	Automated External Defibrillator
AHA	American Heart Association
ALS	Advanced Life Support
CA	Cardiac Arrest
CGI	Cell Global Identity
CI	Confidence Interval
CPR	CardiopulmonaryResuscitation
DNR	Do Not Resuscitate
ECG	Electrocardiogram
EMS	Emergency Medical Service(s)
ERC	European Resuscitation Council
GIS	Geographic Information System
HLR	Home Location Registry
ICD	Implantable Cardioverter Defibrillator
OHCA	Out-of-Hospital Cardiac Arrest
OR	Odds Ratio
PAD	Public Access Defibrillation
PEA	Pulseless Electric Activity
ROSC	Return of Spontaneous Circulation
SALSA	Saving Lives in the Stockholm Area
SCAR	Swedish Cardiac Arrest Register
VF	Ventricular Fibrillation
VT	Ventricular Tachycardia
MPS	Mobile Positioning System
SCD	Sudden Cardiac Death
SCA	Sudden Cardiac Arrest
SMS	Short Message System
TA	Timing Advance

1 INTRODUCTION

Sudden cardiac arrest (SCA) is a condition in which the circulation of blood and oxygen suddenly ceases due to loss of mechanical heart function. Without immediate treatment death is inevitable.

In most cases cardiac arrest occurs outside hospital and far from advanced care. For every minute that passes, the chance of survival decreases substantially. Time to treatment by way of the initiation of cardio-pulmonary resuscitation (CPR) and by applying an electrical shock (defibrillation) to restart the heart, is the most important factor for survival.

The Emergency Medical Services (EMS)s has traditionally been the only resource available for treating out-of-hospital-cardiac arrest (OHCA) patients. In most settings only 1 out of 10 survives, mainly due to long time intervals from arrest to initiation of treatment.

To significantly decrease time intervals and to start lifesaving measures within the first few minutes other ways may be explored on order to reach these patients earlier.

Bearing in mind the current low survival rates and the number of patients suffering out-of-hospital cardiac arrest worldwide, this area of medical research has huge potential for improvement and many more lives could be saved.

2 RESEARCH QUESTION AND RATIONALE

OHCA is a healthcare issue of huge proportions. Low survival rates, from a general perspective, have been unchanged for several decades. Shortening time to defibrillation and initiation of bystander CPR are by far the most important factors for improved survival.

In Sweden, nearly 3 million people are trained in CPR and there are about 25 000 public automated defibrillators (AEDs) throughout the country. Despite this, most AEDs remains unused and most people will never use their CPR skills in real life.

My research questions are therefore*:*

Can resources such as AEDs and lay responders with training in CPR and AED use be located and recruited to the scene of suspected OHCAs? Are current systems, definitions and treatment strategies sufficient and optimally designed to provide early defibrillation and bystander CPR?

This thesis analyses the epidemiology of the population of OHCA patients that are traditionally defined as available for Public Access Defibrillation (*Study I*). In *Study III*, different strategies for defibrillation are analysed and applied to this group of patients. In *Study II* and *Study IV* a new technology for geographical localization and recruitment of lay volunteers to suspected OHCA is evaluated and stands as a potential model for increasing bystander CPR and early defibrillation.

3 AIMS

The overall aim of the current work is to explore different strategies for increasing CPR and early defibrillation in OHCAs with special focus on new technology for localisation and recruitment of lay responders to nearby cases of cardiac arrest. The aim is also to explore the epidemiology in the population previously defined as potential subjects for public access defibrillation (PAD) and to investigate the limitations of such a definition.

Additional and study-specific aims were:

- To describe changes in characteristics and outcome among patients defined as potential subjects for PAD during a 14-year period in Sweden.

- To evaluate the impact on survival among patients available for PAD from three different defibrillation strategies; (1) on-site defibrillation, (2) defibrillation by first responders and (3) defibrillation by the emergency medical services (EMS).

- To evaluate if mobile phone technology and mobile positioning systems (MPS) can be used to identify lay responders and recruit them to the scene of nearby OHCAs prior to ambulance arrival.

- To evaluate if mobile phone technology can be used to increase the proportion of bystander CPR by identifying lay responders and recruiting them to the scene of nearby OHCAs prior to arrival of ambulance, fire and police services.

4 EPIDEMIOLOGY OF OHCA

4.1.1 Definitions

Through the years several different definitions of sudden cardiac death (SCD) have been proposed. It is still elusive and there are no absolute and clear-cut criteria defining the condition. The temporal definition and cause of the event has been the subject of discussions[1]. Currently, SCD is usually described as:

"The unexpected natural death from a cardiac cause within a short time period, generally one hour from the onset of symptoms, in a person without any prior condition that would appear fatal"[2].

Sudden cardiac arrest taking place outside hospital is referred to as out-of hospital-cardiac arrest (OHCA).

4.1.2 Incidence

Death from cardiovascular disease is the most common cause of death in the world with an estimated number of 17.3million annual deaths[3]. In 7.1 million of these, death is caused by coronary heart diseaseand in about one half of these, death occurs as a result of a SCA[4].

In approximately 60-70% of all cases of OHCA the cause is coronary artery disease[5,6] and in about two-thirds of these, SCD is the first presentation of symptoms[7].

There are several complicating factors when defining and comparing the incidence of OHCA. Incidence is defined as the occurrence rate per year of a disease for a population at risk. Usually the adult population is used when calculating incidence rate. The strong correlation between OHCA and age[8] makes it difficult to define the population at risk since OHCA is uncommon at younger ages[9].

Not all OHCAs are treated by the EMS. This can be due to ethical reasons such as declaration of "do not resuscitate orders" (DNRs) and if the EMS crew decides to initiate resuscitation or not. The incidence of EMS-treated OHCA is therefore an important factor when comparing different EMS systems.

Incidence rates differ significantly between countries and within regions as a result of different geographical, ethical and cultural factors, as well as organisation of the EMS. In a systematic review, Berdowski et al. included a large number of studies from four continents. The incidence of EMS-treated all cause OHCA ranged from 41/100 000 in Asia to 51/100 000 in Australia[10]. In a similar review by Atwood and colleagues including European OHCA studies with presumed cardiac aetiologies an overall incidence of 38/100 000 (range 37-46/100 000) was found in the adult population[11].

Based on estimates in this study there are 275 000 EMS-treated OHCAs in Europe annually. In the United States the corresponding number is reported to be as high as 450 000 per year[12]. In Sweden there was 4872 cases of EMS-treated all cause OHCA in 2012. This translates to an incidence of 51/100 000 for all ages and 80/100 000 for ages above 25 years of age[13,14]. In Stockholm the reported incidence is 46/100 000 for all ages.

4.1.3 Causes

In OHCA, the aetiology of the event is often multifactorial and difficult to establish even in post-mortem analysis[15]. Most deaths occur in the pre-hospital settings and there may be lack of information about preceding symptoms and co-morbidities. The cause of the arrest is mostly based upon the clinical judgement of the EMS crew and is clinically divided into non-cardiac or cardiac causes[16].

OHCA can entirely or partly be caused by numerous reasons not primarily due to cardiac disease[17]. Cardiac causes of SCD can be attributable to a wide array of cardiac diseases. Cardiac and non-cardiac causes of OHCA are displayed in Table 1.

Table 1. Cardiac and non-cardiac causes of OHCA

Cardiac causes of OHCA
Ischaemic cardiac disease (coronary artery disease)
Ischaemic cardiomyopathy
Dilated cardiomyopathy
Hypertrophic cardiomyopathy
Non-atherosclerotic disease of coronary arteries
Valvular heart disease
Arrhythmogenic right ventricular cardiomyopathy
Infiltrative and inflammatory myocardial disease
Congenital heart disease
Primary cardiac electrical abnormalities
Non-cardiac causes of OHCA
Pulmonary embolism
Lung disease (hypoxic cause of cardiac arrest)
Electrolyte abnormalities
Bleeding, traumatic/non-traumatic
Subarachnoid haemorrhage
Drug overdose
Suffocation
Drowning
Sudden infant death syndrome

Adapted from Hollenberg J, 2013[18]

Autopsy studies have shown that the proportion of cases of OHCA caused by cardiac disease is somewhere between 55% to 65%[19,20] and that coronary artery disease is the most common cause of the arrest. Farb and colleagues performed post-mortem angiography using 90 hearts from patients suffering SCD. In 57%, acute changes in coronary plaque morphology were found.[21]

In a study by Thomas and co-workers, 350 cases of SCD were examined. Ischaemic heart disease was found to account for 59% of all deaths[22]. In a study by Di Maio of 1000 consecutive autopsies, cardiovascular disease was responsible for 61% of all deaths, with coronary artery disease as the main cause [23].

The reported proportion of OHCA clinically judged to be due to cardiac aetiology varies[24,25]. Only clinical assessment may give an overestimate of the proportion of cases of OHCA judged to be of cardiac origin. OHCAs due to non-cardiac causes may be missed in about one third of cases and diagnosis may only be revealed by autopsy[26].

Non-traumatic OHCAs due to non-cardiac origin is reported to represent 34% to 18% of cases[27,28,29] and are mostly attributable to respiratory disease, pulmonary embolism, drowning, suicide or intoxication.

4.1.4 Risk factors

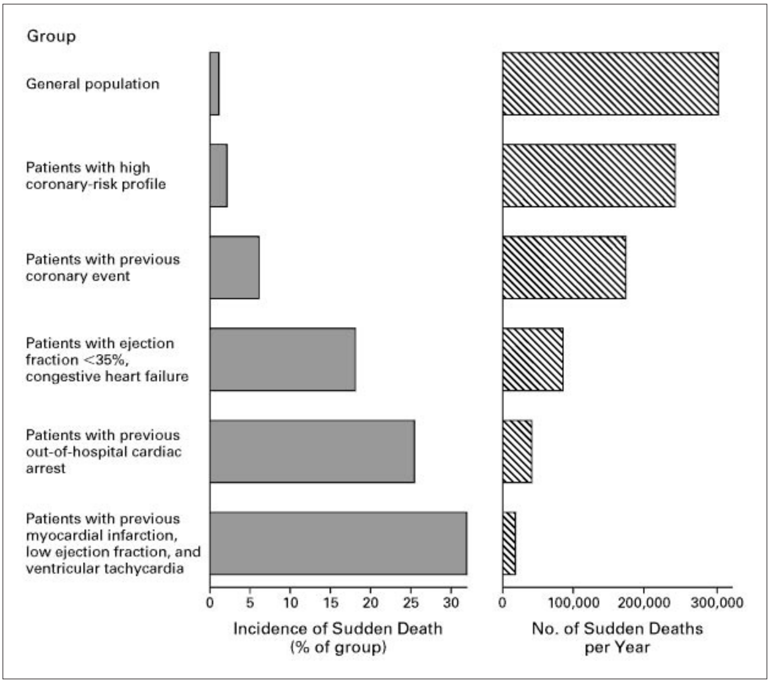
Since cardiac disease is the most common cause of OHCA, risk factors of sudden cardiac arrest naturally share the same properties as those associated with ischaemic heart disease[30,31]. Known risk factors of SCD are summarized in Table 2.

Table 2.Risk factors associated with SCD

Risk factors of sudden cardiac death
Low ejection fraction Congestive heart failure
Coronary artery disease (prior MI, acute coronary syndrome)
Prior cardiac arrest
Smoking Diabetes Hypertension Obesity Autonomic factors Drugs Hypercholesterolaemia Air pollution
Genetic disorders *-Cardiomyopathies* *-Primary electrical abnormalities* Congenital heart disease

The problem of predicting SCD at an individual level is that patients known to be at high risk constitute only a small proportion of all patients[32,33] (Figure 1). The number of patients suffering SCD in the general population without identifiable high risk factors is much greater than the number of patients with identifiable conditions with a high probability of suffering SCA.

Figure 1. The Incidence of Sudden Death in Specific Populations and the Annual Numbers of Sudden Death



With permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Myerburg, Circulation, 1998

4.1.5 Measuring outcome in OHCA

Survival is the benchmark when studying outcome and EMS performance. Surrogate outcome measures that are frequently used are return of spontaneous circulation (ROSC), and admission to hospital. In recent years the importance of also assessing neurological performance in survivors have been stressed[34]. Survival rates vary within and between countries and regions[35,36]. There are numerous factors affecting survival rates and some of them will be described below. Several of the factors affecting outcome in OHCAs are interdependent in a complicated manner. Definitions, variables and measurements also diverge between different settings. In order to bring coherency to definitions, data and outcomes, the “Utstein” (named after the abbey in which the template were formulated) - guidelines regarding reporting of data from resuscitation were formulated in 1991[37]. The Utstein template has become widely accepted worldwide.

Survival rate can be expressed as the proportion of patients surviving in relation to the total number of patients suffering OHCA. Since survival is generally low, around 5-10%, the size of the numerator will have a large impact on survival rate. Defining the numerator is a source for selection bias that can affect survival rates profoundly.[38]

4.1.6 Initial arrhythmia

An arrhythmic SCD can be seen as a result of a complicated interplay of different and multiple risk factors, both transient and chronically occurring[39].

The electrical pattern recorded on the first electrocardiography (ECG) is a strong predictor of survival[40,41]. It may display one out of four types of pattern: ventricular fibrillation (VF), pulseless ventricular tachycardia (VT), asystole or pulseless electrical activity (PEA). By applying an electric shock to chest (defibrillation) VF and VT may be reversed to normal heart rythm. Asystole is the lack of electrical activity in the heart, whereas PEA is electrical activity without any signs of mechanical circulation. The latter two arrhythmias are associated with a much poorer prognosis[42,43] and cannot be treated with defibrillation.

4.1.6.1 Ventricular fibrillation

Ventricular fibrillation can be described as the occurrence of “electrical storms”, resulting in poorly synchronized and inadequate myocardial contractions (fibrillation) and loss off pump function. VF can be triggered by several reasons including acute myocardial ischemia, myocardial scarring and primary electrical diseases[44].

The arrhythmia originates from a substrate of myocardial cells with impaired integrity. A critical mass of myocardium with altered conduction velocity and refractoriness produces re-entry circuits that can spread to adjacent myocardium[45].

The “true” proportion (or incidence) of patients suffering OHCA with a primary rhythm of VT or VF is unknown. In the great majority of cases, there is no way to record the event. However, if an AED is applied within the first few minutes, the proportion of VF can be as high as 65%[46,47]. VF amplitude decreases over time and then eventually deteriorates into asystole[48]. The incidence of VF is therefore also a function of the performance of the EMS system and there is a strong association between time intervals and VF incidence[49]. It is therefore reasonable to assume that the initial VF incidence immediately after arrest is higher than the proportion registered by the EMS.

Authors such as Holmberg et al. have tried to estimate the “true” proportion of patients with initial VF or VT. From known VF incidence in connection with different EMS response time intervals extrapolation was performed and initial proportion of VF was calculated to be as high as 85%[50]. The incidence of VF as first rhythm registered varies but is reported to be 17/100 00 years in Europe and 21/100 000 years in the US[51,52]. There is evidence of a decreasing incidence over the last few decades with a nearly 50% reduction[53,54] since the mid 1980s [55,56,57].

There is an association between life threatening tachy-arrhythmias and left ventricular hypertrophy of any cause[58,59]. In selected individuals ICDs can be used both for primary and secondary prevention of SCD[60]. Patients with reduced ejection fraction of any cause are also at risk, and can according to current guidelines and different patient characteristics, be treated with ICDs[61].

4.1.6.2 Asystole and Pulseless Electrical Activity

Asystole is the lack of electrical activity at ECG and is considered as a sign of a dying heart. Survival in patients presenting with asystole is reported to be very low, 0-5%[62]. Pulseless electrical activity (PEA) is the presence of an organized rhythm at ECG with no signs of a detectable pulse or adequate cardiac contractions. There is a wide array of conditions causing PEA both due to cardiac and non-cardiac diseases (cardiac tamponade, pulmonary embolism, shock of any kind and myocardial ischaemia) but extra-cardiac causes are predominant[63]. Survival after PEA is virtually the same as for asystole[64].

4.1.7 Location

Most OHCA occurs at home. The proportion is reported to be 60%-80%[65,66]. Several known and probably unknown variables that predict outcome are associated with location both in residential location and outside home. Characteristics that may affect outcome such as, social factors, witness status, initial rhythm, EMS response time, AED accessibility and bystander CPR differs dependent on location[67,68]. OHCA victims with advanced age with several co-morbidities and low physical capabilities are more prone to suffer an un-witnessed arrest at home compared with physically active persons[69]. Several studies have shown a relationship between location and survival and even corrected for other variables and location outside home seems to be an independent predictor of survival[70].

In a study carried out by Weisfeldt et al., it was found that OHCA victims collapsing in public places have increased chances of survival, receiving bystander CPR, being witnessed, being of lower age, having an AED applied with shock delivery and to having an initial rhythm of VF/VT. Further, when corrected for different variables, collapsing in public was independently associated with an increased proportion of VF/VT[71].

4.1.8 Witness status

In about two-thirds of all cases the OHCAs are witnessed (i.e. seen or heard by another person)[72]. It is logical that witnessed arrests are associated with better outcome than unwitnessed since prompt recognition and treatment only is possible if the event is seen or heard. Witness status has consistently been proved to be an important predictor of outcome[73,74] and is associated with a nearly three-fold increase in survival[75]. In the Swedish

Cardiac Arrest Registry (SCAR) the proportion of bystander witnessed cases was 54% and EMS witnessed cases was 14%[76].

4.1.9 Age and gender

Age is a risk factor for cardiac disease and subsequently also for SCD. As an independent predictor of outcome the association is weaker. In direct comparison it is associated with worse long time survival and quality of life in patients over 65 years[77]. The incidence of cardiac disease and risk for fatal events is higher in men compared with women in the same age[78]. As a reflection of this, women are suffering OHCA at a greater age compared with men. Characteristics are different in regard to location, witness status, bystander CPR and initial rhythm and are all not in an advantage of improved survival[79].

5 TREATMENT OF OUT OF HOSPITAL CARDIAC ARREST

5.1.1 Prevention

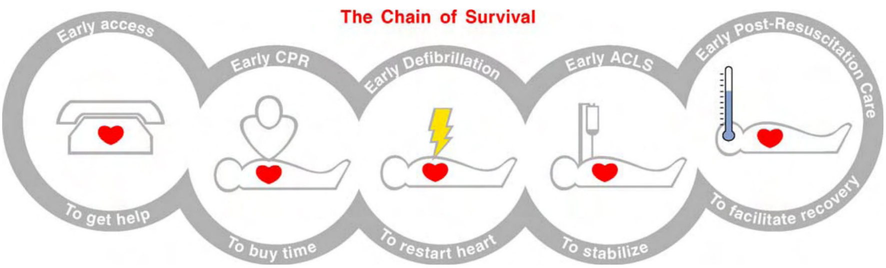
Most patients suffering OHCA have no or unspecific symptoms before the arrest[80] and most healthy individuals and individuals at low and moderate risk do not suffer from OHCA (Figure 1). Primary (avoiding CA) prevention of individuals at risk by way of affecting known risk factors is an important measure. Patients with a low left ventricular ejection fraction, previous SCA, cardiomyopathies or electrical conduction disorders can all (on the basis in individual selection criteria) be subjects suitable for ICDs both for primary and secondary (avoiding recurrent CA) prevention[81,82].

5.1.2 The chain of survival concept

From decades of resuscitation research a few key elements that affects survival in OHCA have been identified. In an American Heart Association (AHA) statement from 1995, Cummins and colleges presented the "chain of survival" concept with the aim of improving survival from OHCA[83]. (Figure 2). This is a still a valid and well-established paradigm made up of (1) early recognition of symptoms and call for help (2) early CPR (3) early defibrillation (4) advanced life support (ALS).

The chain of survival concerns the pre-hospital phase in the treatment of OHCA patients. Recent, the in-hospital phase of the treatment of these patients also attracted much attention and has led to an update of the "chain of survival" adding a fifth (5) link of post resuscitation care.[84]

Figure 2. The Chain of Survival



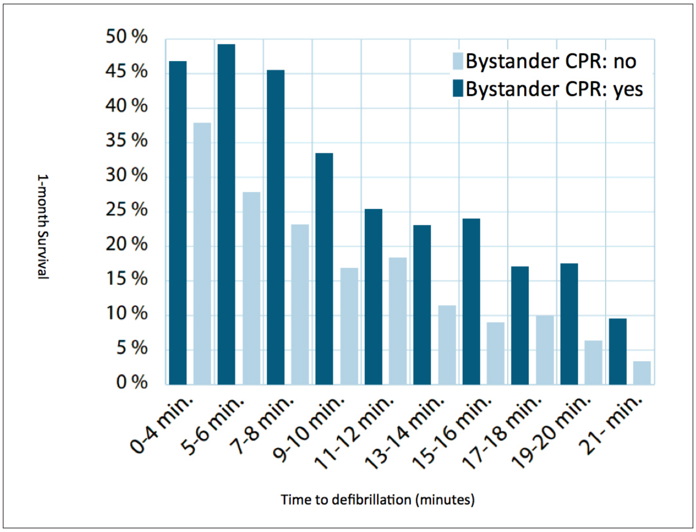
5.1.2.1 Early access, recognition and call for help

Without recognition of a cardiac arrest (CA) or preceding symptoms, appropriate actions such as a call for help and start of CPR will not be undertaken[85]. This is by no means straightforward and there are obstacles to overcome for untrained witnesses or relatives in stressful situations as well as for dispatchers[86,87]. Recognition of CA by dispatchers is difficult, due to the wide array of information given from witnesses[88], but it is important in the context of telephone-guided CPR to untrained helpers[89]. A widespread misconception is that CA-patients do not breathe[90]. In recent years, awareness of agonal breathing (or gasping) has increased and it is recognized that about 40% of all victims of OHCA have some kind of breathing activity[91].

5.1.2.2 Early Cardio-Pulmonary Resuscitation (CPR)

CPR is any form as chest compression or ventilation. Bystander CPR before arrival of the EMS is independently associated with an up to threefold increase in survival[92,93]. For every minute that passes after a cardiac arrest without defibrillation chances of survival decreases by approximately 10-12%[94,95]. When bystander CPR is provided while waiting for defibrillation, the decrease in survival is more modest and averages 3–4%, thus acting as a bridge to defibrillation[96]. Figure 3 is based on data from the SCAR. It shows the important association between CPR and survival independent of the time to defibrillation.

Figure 3. Survival to 1-month in VF/VT patients with or without bystander CPR



Adapted from the Swedish Cardiac Arrest Register with kind permission from J.Herlitz[97].

The mechanisms behind the association with increased survival are probably multiple. Different theories have been launched to explain the hemodynamic effects of chest compressions[98, 99]. Chest compression increases pressure in the thorax and compresses the heart[100]. Decompression creates low or negative intra-thoracic pressure that augments venous return.

Compressions can increase intracoronary pressure, and systemic systolic pressure can reach nearly normal values[101]. As a result of to nearly absent diastolic pressure, blood flow is low but provides critical circulation to the brain and prolongs the time window of irreversible brain injuries due to anoxia[102,103].

Steen et al. observed that within minutes after induced VF, venous return caused distension of the right ventricle and intracoronary pressure dropped. Increased intracoronary perfusion pressure during CPR was associated with increased likelihood of successful defibrillation and achieving ROSC [104,105]. In a randomized controlled trial by Wik et al., VF patients were randomized to either immediate defibrillation or 180 seconds of CPR prior to defibrillation. In the subgroup of patients with response time > 5 minutes survival increased if CPR was performed prior to defibrillation[106].

Intracoronary pressure drops rapidly even after short interruptions in compressions[107]. This can explain the findings that the duration of hands off time and shallow chest compression both before and after defibrillation is associated with unsuccessful defibrillation[108].

In the current European resuscitation guidelines, a chest compression to ventilation ratio of 30:2 with a compression rate of 100 per minute and at a depth of at least 5 cm (in adults) is recommended. As regards untrained bystanders or bystanders not willing to perform ventilation only chest compression is recommended[109]. This is different to the 2005 guidelines, which advocated a 15:2 ventilation to compression ratio[110].

Ventilation as a part of the CPR algorithm is being questioned and is even not a part of the training and recommendations in some settings. Instead cardio-cerebral resuscitation is used as a term and preferred concept[111,112]. There are several physiological arguments for this approach plus the removal of psychological barriers that stand in the way of bystander actions[113].

In the case of dispatcher telephone-assisted CPR given to lay rescuers without prior CPR training, two large randomized controlled trials showed no benefit of compression and ventilation combined versus compressions alone[114,115]. However, a meta-analysis combining the two studies showed a significant benefit of compression-only telephone- assisted CPR[116].

There is further epidemiological data supporting the idea of completely leaving out ventilation in the context of basic life support. Several large observational trials from Japan and the US reports at least equal benefit of compression only-CPR compered with standard CPR[117,118].

There is evidence of poor quality-CPR carried out by medical professionals[119,120]. Interruptions in chest compressions due to intravenous needle placement, drug administration, intubation, rescue breathing and other measures are common. Despite the fact that high quality CPR never directly been proven to have impact in survival much hope has been put into the development of mechanical chest compression devices. Two large randomized controlled trials, in which manual CPR was compared with mechanical chest compressions, have shown no additional benefit of mechanical compressions compared with manual compressions[121,122].

5.1.2.3 Early defibrillation

The only effective treatment of OHCA can exclusively be offered to those patients with an initial rhythm of VF/VT. Defibrillation is the key link in the chain of survival and is virtually the only intervention that can reverse a cardiac standstill due to VF/VT and restore normal rhythm and circulation[123]. As shown in Figure 3, the chance of successful defibrillation and survival decreases by approximately 10% for every minute after a cardiac arrest in patients in patients found in VT/VF[124]. Additionally the incidence of VF/VT decreases with time and many patients with initial VF/VT are lost as the arrhythmia transforms into a non-shockable rhythm[125]. This "double effect" makes time from cardiac arrest to first rhythm analysis and possible defibrillation even more crucial and the importance of reducing time intervals from arrest to defibrillation may be the key to further increase survival in OHCA[126,127].

The Automated External Defibrillator (AED)

In the past, defibrillation was a complicated and only performed in hospital by medical doctors. In the late 1980s the first reports of safe successful implementation of AEDs pre-hospital settings were published[128,129]. Since then AEDs have undergone substantial technical evolution, although the functionality is the same. Today, AEDs are small, durable, easy to use and inexpensive. The AED is equipped with adhesive pads and a microprocessor with an algorithm for discrimination between VF/VT and organised rhythm. The algorithm for detecting shockable rhythms has continuously been refined and is approaching 100% in sensitivity and specificity[130,131]. AEDs usually give audiovisual guidance for electrode placement, CPR and defibrillation to bystanders or medical personnel and the can be used by both trained and untrained non-traditional medical responders.

Public Access Defibrillation (PAD)

Successful and safe implementation of AEDs in pre-hospital settings and use by non-medical professionals such as flight attendants, police officers and security guards has been confirmed in several studies[132,133,134]. The American Heart Task Force on "Future CPR" first formulated PAD as a concept in 1990[135] promoting widespread implementation of AEDs at different levels of society, also including AEDs in public places that may be operated by trained or untrained civilians in order to decrease time to defibrillation.

Levels of PAD

Four levels of PAD responders that have previously been defined[136] are outlined in Table 3.

Table 3. Levels of PAD responders

Level	Label	Example	Description	Trans-ported	OHCAs at home	Trained
1	Traditional first-responders	Police, fire-fighters	Dispatched units	Yes	Yes	Yes
2	Non-traditional first-responders	Lifeguards, security personnel, flight attendants	Trained personnel with "duty to respond"	No	No	Yes
3	Lay persons	Persons of trust, sport coaches	Trained and committed civilians	No	No	Yes
4	Lay persons	Occasional bystander (Fire extinguisher analogy)	Civilians with/without training	No	No	No/Yes

Traditional first responders

Dual dispatch of AED-equipped police or fire units in parallel with the standard EMS has been evaluated in several observational before and after studies[137,138] with variable designs. In some studies increased survival was seen in the subgroup of VF patients[139] as well as in all rhythms[140]. The most randomized-like designed study so far has been carried out by van Alem and colleagues. A crossover design was used with the aim of evaluating police as first responders. A significant reduction in time from collapse to defibrillation was seen in favour for dual dispatch, 668 seconds vs. 769 seconds ($p<0.001$). There was an increased rate of ROSC observed, but no significant difference in survival was detected between groups[141].

Non-traditional first responders

As the concept of first responders was accepted, it became natural to expand PAD to involve lay responders with a "duty to respond". This usually includes security officers, lifeguards and flight attendants. Several studies have been published in this area and they highlight the importance of rapid defibrillation for survival and the potential in this approach. Page et al. reports from a study in which all American Airlines aircrafts were equipped with AEDs. A total of 24 000 flight attendants were trained in CPR and AED use.

In a 2-year period, 15 patients received shocks. In 13 cases of documented VF and in 2 cases of presumed VF. Forty per cent survived with full neurological recovery[142].

Another landmark study published by Valenzuela et al. involved security officers in 32 casinos trained in CPR and AED use[143]. The trained response and AEDs was encouraged to be no more than 3 minutes away in case of a CA. A total of 148 prospectively collected cases of OHCA were included. In 105 cases the initial rhythm was VF and of these, the survival rate was 56%. In cases defibrillated within 3 minutes survival was 74%.

Lay persons with training

Aircrafts, airports and casinos are all enclosed and easily controlled public settings. The randomized controlled PAD-trial was a huge effort to evaluate the more widespread dissemination of AEDs to the next level of responders and to include residential areas[144]. In 24 cities throughout the US and Canada, both in public places and in residential areas, lay responders were trained either in CPR alone or in CPR and AED use. A total of 1600 AEDs were distributed and 20 000 lay responders in 993 different units were trained in CPR, or CPR plus AED use. There were 235 definitive OHCAs during the study. Survival was doubled, with 31 cases surviving in the CPR plus AED arm versus 16 cases in the CPR-only arm, RR 2.0 (CI 1.07-3.77). Nearly all survivors suffered arrest in a public location and there were only 2 survivors from OHCAs in residential locations.

In the Home AED Trial (HAT) 7001 patients were followed for a median of 37 months. It was designed as a randomized controlled trial with the aim of evaluating the effect on survival of AEDs use at home in patients with an increased risk of sudden cardiac death[145]. Patients with previous anterior-wall myocardial infarction, not candidates for an implantable cardioverter defibrillator, (ICD) were included. Additionally, a spouse or companion willing to call for assistance, carry out CPR and use an AED was needed. Patients were randomly assigned to CPR or CRP plus AED use. There were 160 deaths considered to be due to VF/VT. In the AED group, shock was delivered in 12 patients with 4 subsequent survivors. The results showed no difference between groups in the primary outcome of death from any cause.

Lay persons without training

The supportive features of AEDs have made it possible for people with little or no training to use one. In a study carried out in airports in the Chicago area with about 100 million passengers passing through each year, AEDs were placed in cabinets throughout the terminals, allowing retrieval within 3 minutes maximum[146]. The use of defibrillators was promoted by way of public-service videos in waiting areas, pamphlets, and reports in the media. There were 21 cardiac arrests in 2 years. Ten of the 21 patients survived. In half of all cases the rescuer had no prior training in AED use.

Structured PAD programs and "Wild AEDs"

In 2006 the estimated number of AEDs sold in the U.S. was 200 000, a tenfold increase in 10 years[147] and there is an estimated number of 1 million AEDs in the US only.

Most AEDs are bought through private initiatives and disseminated in a non-structured manner. Little is known about AED usage and impact on survival "in real life" beyond a controlled study environment.

In a structured PAD programme, typically high incidence sites are identified[148], a trained response to suspected OHCAs is implemented and events are carefully monitored. In the case of "Wild AEDs" they are "bought over the counter" through private initiatives, often without audit. In an Austrian Red Cross countrywide initiative PAD-programme (ANPAD), AEDs were sold in an "over-the-counter"- like fashion to private initiatives together with a training and maintenance offer. In retrospective follow-up of 1865 installed devices over 2 years, 62 cases of AED attachment were identified, 27 patients were shocked and 17 survived (27%). A baseline survival rate of 4.3% was used as reference[149].

In a retrospective study based on 13 769 out-of-hospital cardiac arrests from the Resuscitation Outcomes Consortium (ROC) registry, the impact of community-wide dissemination of AEDs in both Canada and in the US was evaluated[150]. In 289 cases (2.1%) an AED was applied before EMS arrival and in 35% of these lay responders attached the AED. Overall survival was 7% compared with a survival rate of 38% (64 of 170) if a shock was delivered before EMS arrival. Kitamura and colleagues reported that the number of publicly accessible AEDs in Japan grew from 9906 in 2005 to 88265 in 2007, a nearly 900% increase in 3 years. During this period there were 307 925 EMS treated OHCAs and 462 patients were shocked with a public AED. As the numbers of AEDs increased, there was a concurrent increase in patients receiving shocks from public AEDs, from 45 annual cases in 2005 to 274 cases in 2007. If shocked with a public AED, overall survival was reported to be 37%, (n=172)[151].

5.1.2.4 Advanced Life Support (ALS)

Advanced life support includes advanced airway management (endotracheal intubation or use of a supraglottic airway device) and the use of intravenous drugs. Currently there is no convincing evidence of an additional impact of ALS on survival beyond that achived through basic life support and rapid defibrillation[152,153]. Stiell and colleagues reported no difference in survival in a multicentre, controlled clinical trial conducted in 17 cities before and after advanced-life-support programmes[154]. In a meta-analysis, Bekalos et al. found that in 9 of 18 studies with a total of 7659 patients with CA in the intervention group, ALS care increased survival compared with basic life support (OR 1.5, 95% CI, 1.3–1.7).

Concerns have been raised that a focus on airway management, intravenous access and other advanced measures may take focus and time from basic life support. It is recognized that the hands-off time during CPR provided by the EMS can be as much as 50%[155].

The value of drug administration during CA is unclear. In a randomized trial including 851 patients, Olasvengeen and colleagues evaluated the use of any intravenous (i.v) drug versus no i.v drugs[156]. The results showed no difference in the primary outcome of survival to hospital but i.v administration of drugs was associated with a higher proportion of patients having ROSC. In a SCAR study by Holmberg et al. use of adrenaline was associated with poorer outcome[157] and there are animal studies suggesting that it can affect cerebral blood flow in a negative way and increase ischaemia after restoration of circulation in CA[158].

In CA with refractory VF, current guidelines recommend intravenous amiodarone. Increased survival to hospital admission has been shown in one placebo-controlled randomised trial (44% vs. 34%, p=0.03)[159]. Amiodarone has also been proven to be superior to lidocaine in regard to hospital admission[160]. No drug has yet been showed to have impact on long time survival.

The value of advanced airway management is unclear. The question of what type of device to use, if any, is controversial. In a recent large observational study endotracheal intubation was associated with increased survival compared with use of supraglottic airway device but in patients with no advanced airway management survival was markedly increased compared to patients receiving advanced airway management of any kind[161]. Several other observational studies have shown advanced airway management to be associated with worsened neurological outcome and decreased survival compared with bag-mask ventilation[162,163].

5.1.2.5 Post-resuscitation care

Recently, a statement document from the ERC and the AHA defines *post-cardiac arrest syndrome* as comprising anoxic brain injury, post-cardiac arrest myocardial dysfunction, systemic ischaemia/reperfusion response, and persistent precipitating pathology[164]. The roles of different invasive measures and intensive care treatments have increased in importance and different treatment protocols and prognostication algorithms have been suggested[165,166].

Therapeutic hypothermia

Two randomized controlled trials reports that, in resuscitated witnessed OHCAs with an initial rhythm of VF, induced therapeutic hypothermia (32-34 °C) improved neurological function among survivors[167,168]. Recently, in the largest trial randomized trial so far addressing this issue (including 950 patients) temperature management of 33 and 36 °C for 24 hours was compare and no differences in survival or neurological outcome were found[169].

Current guidelines recommend start of cooling with as little delay as possible[170]. There is no evidence, however, that starting hypothermia post-ROSC with cold i.v fluids in the pre-hospital setting would be beneficial for survival[171,172]. In one study (Kim et al.) there was an increased proportion of pulmonary oedema and recurrent arrests in the group allocated to hypothermia. The value of induction of hypothermia during resuscitation (intra arrest cooling) is yet to be ascertained. Feasibility studies on cooling with fluid as well as nasal evaporative cooling have shown interesting results and on- going trials will add evidence in this regard[173,174,175].

Coronary angiography and acute revascularization

Current guidelines recommend immediate coronary angiography in resuscitated OHCA patients with an ECG pattern of ST-segment elevation myocardial infarction (STEMI) or left bundle branch block (LBBB)[176]. However, in many OHCA patients with non-STEMI, acute coronary occlusions are present and ECG patterns may be a poor predictor of coronary occlusions in CA[177]. Observational studies have demonstrated as association between immediate angiography and increased survival[178,179]. Until we see the results of future trials it is unclear if OHCA patients benefit from an immediate invasive approach.

Other factors associated with outcome in post-cardiac arrest patients

Factors such as fever, high blood glucose levels, elevated serum potassium, acidosis, seizures, hypotension and hyperoxia have been associated with poor outcome[180,181]. Some studies, in which structured protocols have been implemented, have shown improved survival compared with historical controls[182].

6 MATERIALS AND METHODS

6.1 EMS AND DISPATCH SYSTEM

The national emergency number (112) in Sweden is dialled in cases of a medical emergency. The medical dispatch centres are located throughout the country in relation to the density of the population. Emergency calls are handled in accordance to a triage- like and structured medical system with pre-specified questions and actions dependent on the type of emergency.

The Stockholm County covers 6519 sq. km and has population of 2 091 473[183]. The incidence of EMS treated OHCA was 46/100000 in 2011.

In the Stockholm area there is a single EMS dispatch centre receiving all calls within the county. Ambulances are dispatched in a two-tier system and all ambulances are equipped with a defibrillator. An additional ambulance carrying a nurse or a medical doctor trained in anaesthesiology and in ALS is always dispatched to suspected OHCAs. There are about 60 ambulances available for dispatch during the day (7 am to 9 pm) and 40 at night.

6.2 FIRST RESPONDER SYSTEM

At the beginning of the century, the rate of 1-month survival in patients suffering an OHCA in the Stockholm County was as low as 2-3%[184]. To increase survival, the Saving Lives in the Stockholm Area (SALSA) project was launched. The main aim of the SALSA project was to decrease time intervals in OHCA by dual dispatch of fire fighters in parallel with standard EMS. In 2005, all fire stations (n=43) in Stockholm County were equipped with AEDs. All fire-fighters annually underwent eight hours of CPR-training and AED use according to ERC guidelines[185]. Since 2005, dual dispatch of EMS and fire-fighters occurres in response to suspected OHCA-subjects over 8 years of age and not in connection with suicide or trauma. In addition, increasing numbers of police vehicles were also available for dispatch to suspected OHCAs. The number of police vehicles available for dual dispatch increased from 35 at the beginning of 2006 to reach 104 in 2012.

In cases of OHCA in where the fire or police services arrives first at the scene, they performe the medical assessment, started CPR and attached an AED if indicated. Upon arrival of the EMS crew, medical responsibility is transferred to the personnel with the highest medical competence. The first responder system and the results of the SALSA pilot study have been described thoroughly elsewhere[186].

6.3 THE SALSA PAD PROGRAMME

The PAD programme within the SALSA project started in 2005 with a prestart run-in period of one year. In 2005, 30 sites were approached with an offer to participate in the PAD programme. Property owners, site managers and security companies at traditionally high-incidence sites, such as big shopping malls, transportation hubs and airports were targeted. If the site purchased the AED(s), the SALSA PAD-programme personnel agreed to give free instructional training in standard basic life support (BLS) and AED use.

The goal was that each site would be self-supporting in subsequent staff training of BLS and AED use. A formal agreement was signed on behalf of the SALSA PAD- programme and the participating site. The SALSA PAD-programme pledged to support each site and to plan and optimize the local response to suspected OHCA. This included: training of staff, alarm plans, awareness campaigns, signs and official posters as well as AED placement. The site, on the other hand, agreed to have their personnel trained in BLS and AED use with re-training once a year and to report AED usage.

As the number of sites increased to above 60 in 2006 no more active recruitment carried out. From the 2006 participating sites were only recruited on their own initiative and the number of sites increased yearly to reach 135 in 2012.

6.4 THE SMS-LIFESAVER PROJECT

The SMS-lifesaver project first started in 2008 with the aim of investigating if mobile phone technology could be used for increasing survival in OHCAs. The idea was to use the fact that the geographical position of any mobile phone that communicates with the mobile phone network could be obtained at any given moment.

6.5 MOBILE POSITIONING AND DISPATCH OF LAY RESPONDERS

Mobile positioning system

The mobile positioning system (MPS) makes nearly instant determination of the geographical position of a specific mobile phone possible. The accuracy as regards a given position depends on the method that is used for positioning and the number and distribution of the communicating base stations (antennas). In Sweden, the mobile systems offered by the network operators use the GSM (Global System for Mobile Communications) standard[187].

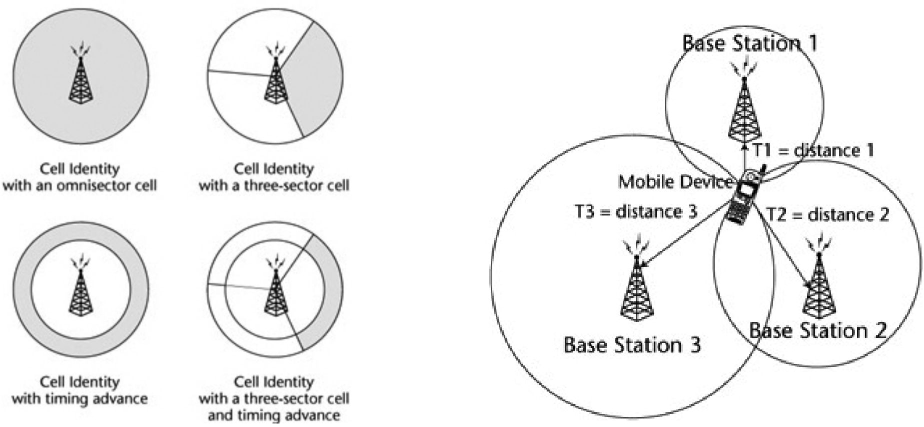
The GSM network uses a hierarchic structure in order to connect the right call to the right user. The “cell” is the smallest unit in the system and covers a specific geographical area that can vary from a few metres (in urban areas) to 35 kilometres. A radio transmitter (base station) that communicates with other parts of the GSM system is placed in the middle of the cell. The cell can have different shapes and be circular or hexagonal. In each cell there are a number of antennas that are used to cover all parts and angels of the cell. In urban areas where buildings and narrow streets are in the way of the radio waves a large number of antennas must be used in every cell. Every cell within the system has a unique identity and a known geographical location.

Mobile phones are constantly communicating with the system when switched on and not only when used for calls or text messaging. Information about the cell in which a specific mobile phone was last “seen” is constantly stored within a database called the HLR (Home Location Register).

There are several (more or less advanced) ways to determine the geographical position of single mobile phones within the GSM system. The technique for enhanced geographical accuracy used in Sweden is called Cell Global Identity and Timing Advance (CGI+TA). The system of unique cell identities makes it possible to determine the approximate geographical position of a single mobile phone user, since the geographical position for every base station and cell is known and every base station and cell has a unique identity that is stored in the HLR.

To identify a mobile phone the data stored in the HLR is used to find out the cell in which the mobile phone is present (CGI) and with what base station the mobile phone is communicating. To increase accuracy the cell is further divided into sectors. Each sector covers a specified area of the cell with a given angle from the base station. It is possible to measure the time it takes for the radio signal from the mobile phone to reach the base station. It is also possible to measure the angle between the communicating antenna and the mobile phone (TA). With this data present a more accurate position of the mobile phone can be calculated.

Figure 4. Mobile Phone Positioning System

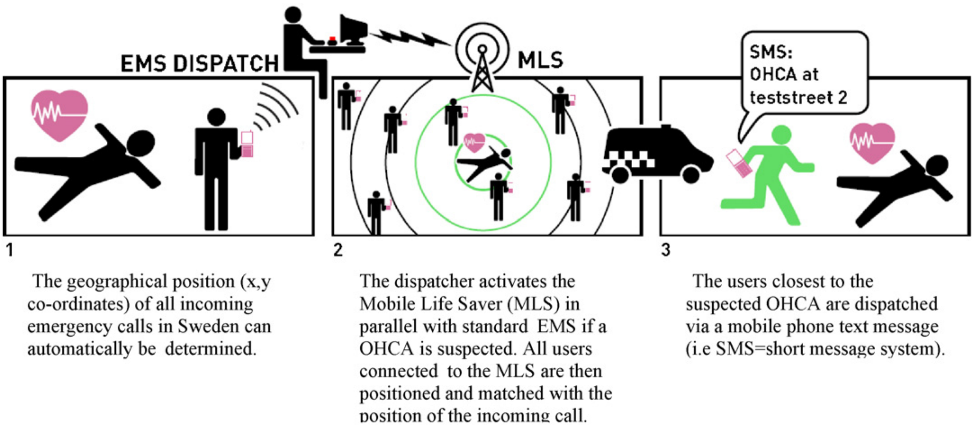


CGI: Accuracy is dependent on the size of the cell and the size of the sector
TA: Accuracy is dependent on the distance to the base station and the size of the sector

Logistics and dispatch of SMS-lifesavers.
Tailored mobile phone services that use MPS to locate selected mobile phone users can be developed for different purposes. A computer-based application for mobile phone positioning and dispatch of lay responders was developed by LEKAB Communication Systems and is referred to as the SMS-lifesaver service. Lay volunteers connected to the SMS-

lifesaver service were called SMS-lifesavers (Mobile Responders (MRs) in *Study II*). The SMS-lifesaver service acts as an interface between the emergency medical service (EMS) data system and the MPS. The SMS-lifesaver service handles the geographical localisation and dispatching of SMS-lifesavers based on the data present in the EMS data system. The geographical location of all incoming calls to all dispatch centres in Sweden is determined. When the dispatcher receives an emergency call from a witness of a suspected OHCA the dispatcher activates the SMS-lifesaver service in parallel with standard EMS and first responders. When the SMS-lifesaver service is activated it uses the MPS to compare the current geographical position of all SMS-lifesavers connected to the SMS-lifesaver service with the location of the incoming emergency call of suspected cardiac arrest. If one or more SMS-lifesavers is present within a radius of 500 m (optional) from the suspected arrest, the SMS- lifesaver(s) receives a cardiac arrest alert with a computer-generated phone call and a text message (i.e. SMS=short message system) with information about the place of the suspected cardiac arrest Additional information can, if needed, be sent to the SMS-lifesavers.

Figure 5. Logistics and functionality of the SMS-lifesaver system



6.6 RECRUITMENT OF LAY RESPONDERS

CPR-trained lay volunteers were recruited to sign up for the SMS-lifesaver service through advertising campaigns in different media and at CPR training courses. Registration for the SMS-lifesaver service was web-based and the following data was entered: age, sex, level of CPR training, date of last CPR training, e-mail adress, and phone number. An informed consent click box stating that the volunteers was over 18 years of age, had former CPR training, agreed upon being positioned and dispatched to suspected OHCAs, and discretion agreement for avoiding harm of third parties was mandatory for registration and activation of the service. No financial or other compensation was offered.

6.7 DATA COLLECTION

6.7.1 Swedish cardiac arrest registry (SCAR)

In all studies presented in this thesis, data from the SCAR was collected. The SCAR is classified as a quality registry by The Swedish Association of Local Authorities and Regions and by the National Board of Health and Welfare. The SCAR was initiated in 1990 and The Swedish Resuscitation Council currently operates the registry. Data about resuscitation measures and outcome of EMS treated OHCAs are continuously reported by the EMS organizations in Sweden. Initially only a few EMS systems participated in the register. At the present time, however, all the EMS systems in Sweden participate. At present, coverage is complete (100%), but there may be incomplete individual reporting. During the time period of *Study 1*, estimations were made that about 70% of all EMS treated OHCAs was reported. Since late 2007, all data are registered on-line by the EMS. Data is reported according to the Utstein Guidelines[188] and this procedure includes the completion of a standard form with a detailed description of the circumstances and interventional actions for each EMS treated OHCA in which any form of CPR was performed. This included variables such as: age, gender, witnessed status, location, bystander CPR, presumed aetiology, initial rhythm, administration of drugs, defibrillation, time intervals, ROSC and 1-month survival.

6.7.2 Ambulance records

For every medical emergency treated by the EMS there is also an ambulance record for documentation of different circumstances concerning the emergency. Signs and symptoms are noted as well as medications, plausible diagnosis and given treatment. Different time intervals such as time of dispatch, arrival at the scene, leaving the scene and arrival at the hospital are also noted.

In *Studies III* and *IV* all ambulance records were a reviewed in addition to data from SCAR. This was made to ensure quality control of data, to collect additional data and to identify cases of OHCA that was not reported to SCAR.

6.7.3 First responder records

All first responders (police and fire services) dispatched to OHCAs within the SASA-project as well as in other parts of Sweden reports in a similar fashion as to SCAR. Reported data is currently stored in the Saving More Lives in Sweden (SAMS) database. There have been extensive manual quality controls, validation and supplementing of the data reported by first responders in the Stockholm County. Data from the SAMS register was used for *Studies III* and *IV*.

6.7.4 SMS-lifesaver survey

For every SMS-lifesaver that was positioned within 500 m of a suspected OHCA a web survey was sent out. If the survey was not answered within one week an additional remainder was sent out. In the web-based survey the SMS-lifesavers answered a number of questions concerning: Was the alarm received and noticed? Did the SMS-lifesaver tried to reach the scene of the suspected OHCA? If so, was arrival at the scene prior to dispatched units. Did the SMS-lifesaver perform CPR and if CPR was first to be performed by the SMS-lifesaver? Internal quality controls indicated a nearly 80% answering rate. The SMS lifesavers were manually followed up (contacted by telephone) in *Study II* and for *Study IV* a web-based survey was used for follow up.

6.8 ETHICS

The Regional Ethics Committee approved all studies. In *Study II, IV*, consent for using patient data was obtained for all patients that were alive at follow-up. For obvious reasons informed consent could not be collected at inclusion and this was accepted by the ethics board. All SMS-lifesavers agreed upon registration that their mobile phones could be located and that information received about suspected OHCAs was not for spread to third parties. Data about positioning was kept for study use only. SMS-lifesavers could at any time erase all data and leave the project. SMS-lifesavers were also available to and get in contact with the project management personnel in case of traumatic experiences. Debriefing was provided when requested by the Stockholm county fire department. The project management team continuously reviewed potential adverse events.

6.9 STATISTICS

For detailed descriptions see the respective studies. P-values are two-sided and were regarded as significant if <0.05. Statistical methods are in summary displayed in Table 4.

Table 4. Summery of statistical methods

	Study I	Study II	Study III	Study IV
Comparisons between two groups:				
Fisher's exact test	X	X		
Chi^2 - test			X	X
Multivariable analysis:				
Logistic regression				X
Trend tests:				
Dichotomous variables:				
The Mann–Whitney ***U*** test	X			
Continuous variables:				
Sperman´s rank correlation test	X		X	

7 RESULTS

7.1 STUDY I

"Out of hospital cardiac arrest outside home in Sweden, change in characteristics, outcome and availability for public access defibrillation"

7.1.1 Main findings

A total of 26% of all OHCAs (10133 patients out of 38710 patients) fulfilled the inclusion criteria (i.e. EMS-treated and occurred outside home) and were considered as potential subjects for PAD. In this group, significant changes in characteristics over time are displayed in Figure 6-8. The proportions of patients found in VF decreased in all patients from 56% to 50%. Survival to one month among all patients increased from 8% to 14% and among patients found in a shockable rhythm survival increased from 15% to 27%. The median time from cardiac arrest to defibrillation increased among witnessed cases from 12 min to 10 min.

Figur 6. Characteristics over time in OHCA patients outside home.

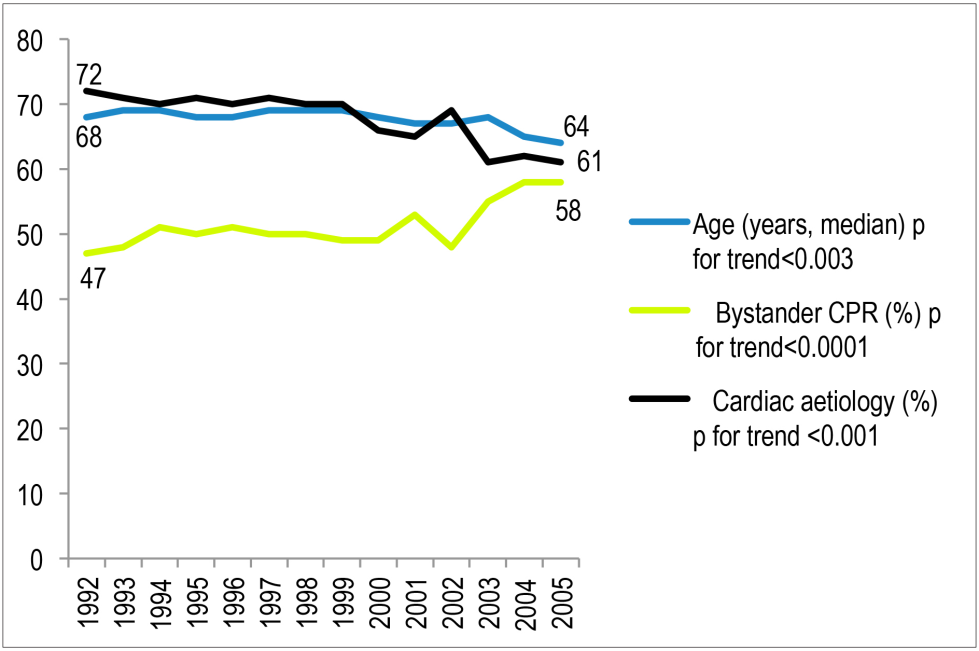


Figure 7. Incidence of VF over time in OHCA patients outside home.

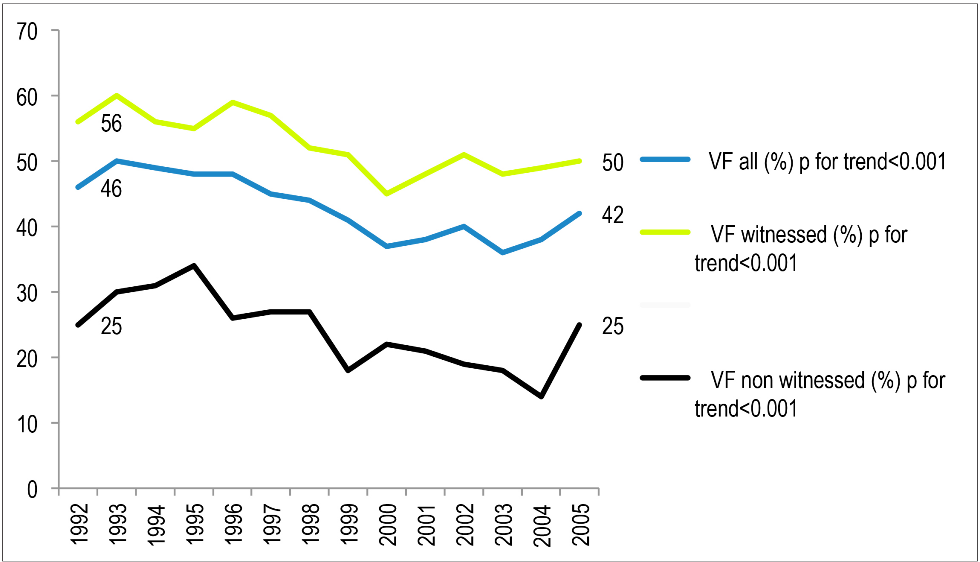
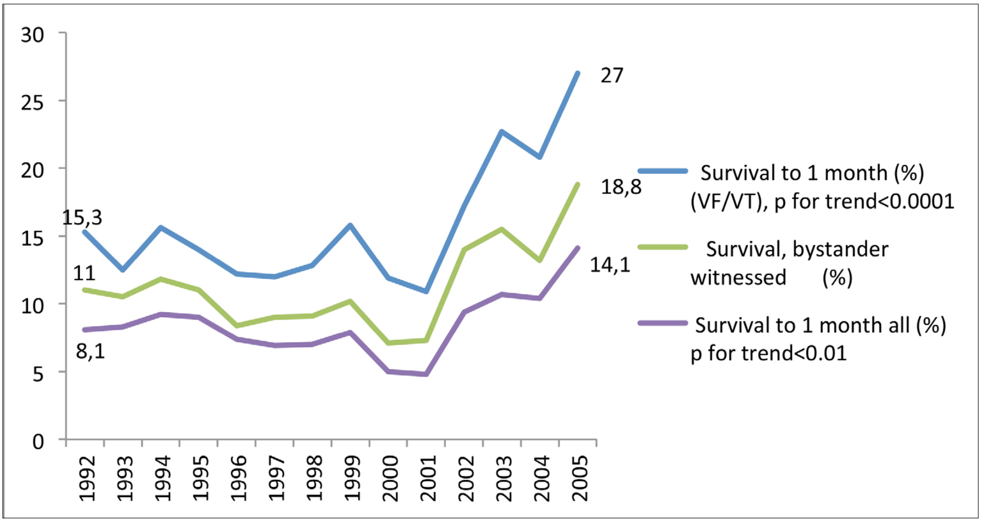


Figure 8. Survival over time in OHCA patients outside home.



7.2 STUDY II

"Mobile phone technology identifies and recruits trained citizens to perform CPR on out-of-hospital cardiac arrest victims prior to ambulance arrival"

At the start of the study 1261 volunteers (SMS-lifesavers) signed up and were connected to the SMS-lifesaver service and the number increased to 1801 during the study.

(In Study II lay volunteers were called Mobile Responders (MRs) and which were later changed to SMS-lifesavers.)

7.2.1 Main findings

Over a period of 25 weeks in downtown Stockholm, 92 cases of suspected OHCA resulted in activation of the SMS-lifesaver service. In 45% (n=41) of all cases one or more SMS-lifesavers reached the location of the suspected OHCA prior to EMS arrival (Table 5). The mean EMS response time in these 92 suspected OHCAs was 7 min and 8 s. In 40% of all calls the suspected OHCA was a true cardiac arrest (i.e. resuscitation attempts were made by the EMS) and amongst these cases one or more SMS-lifesaver(s) reached the place of the arrest prior to the EMS in 56% (n = 20) of the incidents. CPR was performed by SMS-lifesavers in 17% of all true cardiac arrests.

Table 5. Proportion of SMS-lifesavers (Mobile Responders MRs) reaching the scene prior to ambulance

Number of cases = 92	% (n)
First on scene	
MRs first	45 (41)
EMS first/same time as MRs	55 (51)
Proportion of cases with MRs recruited to the scene	99 (91/92)
Mean distance from suspected OHCA for MRs reaching the scene before the EMS	251 m
MRs within 500 m from suspected OHCA on average[a]	
1–3	5 (5)
4–9	37 (34)
>10	58 (52)
Suspected OHCA between 08 and 20	72 (66)
Location of suspected OHCA	
At home	64 (58)
Outside home	36 (33)
Diagnosis of suspected OHCA[a]	
Confirmed OHCA	40 (36)
Other cause/unclear	60 (54)

[a] In one case no MRs were positioned or dispatched; calculations based on the remaining 91 cases. 2 cases with missing data regarding diagnosis, calculation based on the remaining 90 cases.

7.3 STUDY III

"Survival rates after Public Access Defibrillation in Stockholm, Sweden"

7.3.1 Main findings

All OHCAs in Stockholm County in 2006-2012 were eligible for the study. Witnessed arrests outside, home of cardiac origin and with VF or VT were considered to be cases eligible for PAD. The number of PAD sites increased from 60 to 135 during the study. Forty-seven fire and 104 police units were available for dispatch as first responders. The number of "wild" AEDs outside the PAD programme increased from 178 in 2006 to 5016 in 2012. As seen in figure 9, of 6532 OHCAs, 7 % (n=474) were defined as subjects for PAD. Of these, 69 % (n=326) were defibrillated by the EMS, 11 % (n=53) by first responders and 16 % (n=74) by public AEDs. The rate of survival to one month was 71 % (n=51) if defibrillated by a public AED (p<0.001), 31 % if defibrillated by the EMS (n=101) and 42 % (n=22) if defibrillated by first responders. The increase in cases defibrillated by a public AED was correlated with an increase in the cumulative number of public AEDs sold (Figure 11). The number of AEDs within the PAD program was inferior to the number of AEDs outside the program but were used in 28% (n=21) of the cases.

Figure 9. Flow of patients and outcome in Study III.

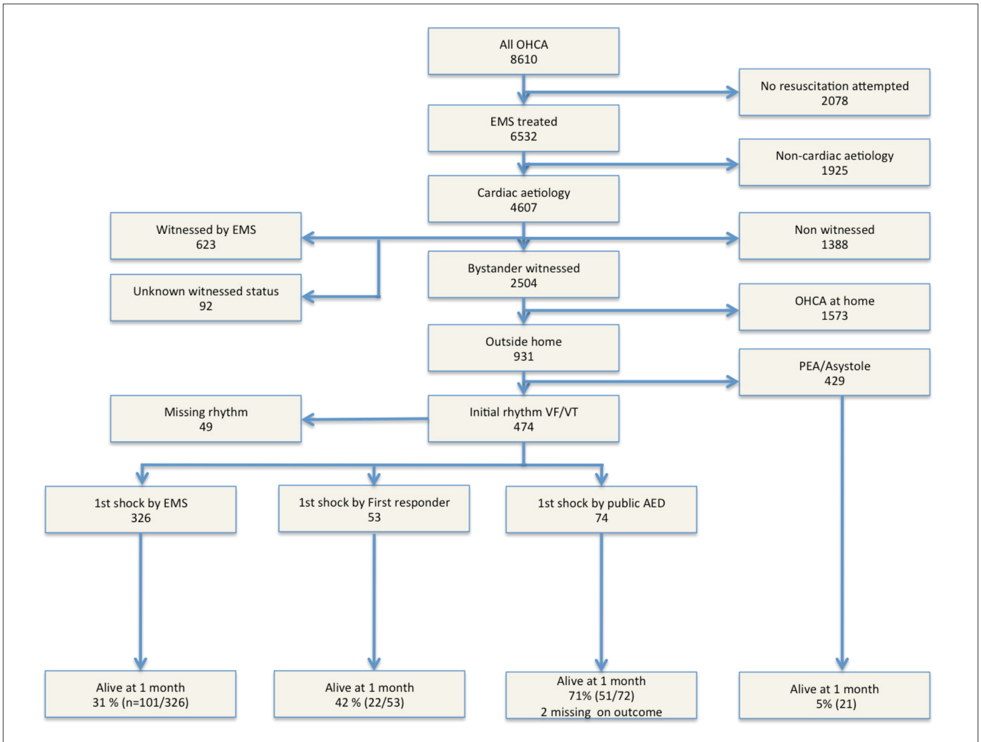


Figure 10. Proportions (%) of patients available for PAD defibrillated by; EMS first responders and public AEDs

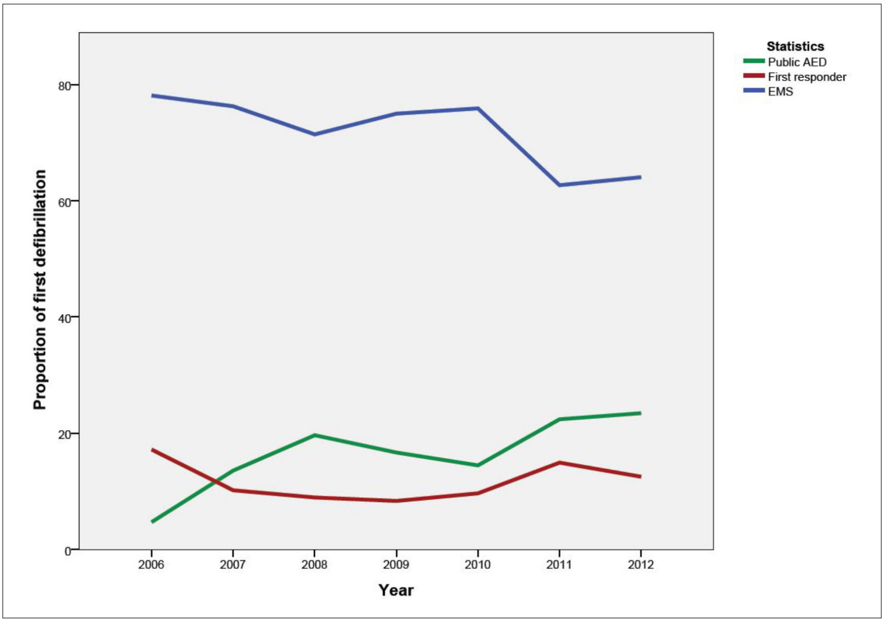
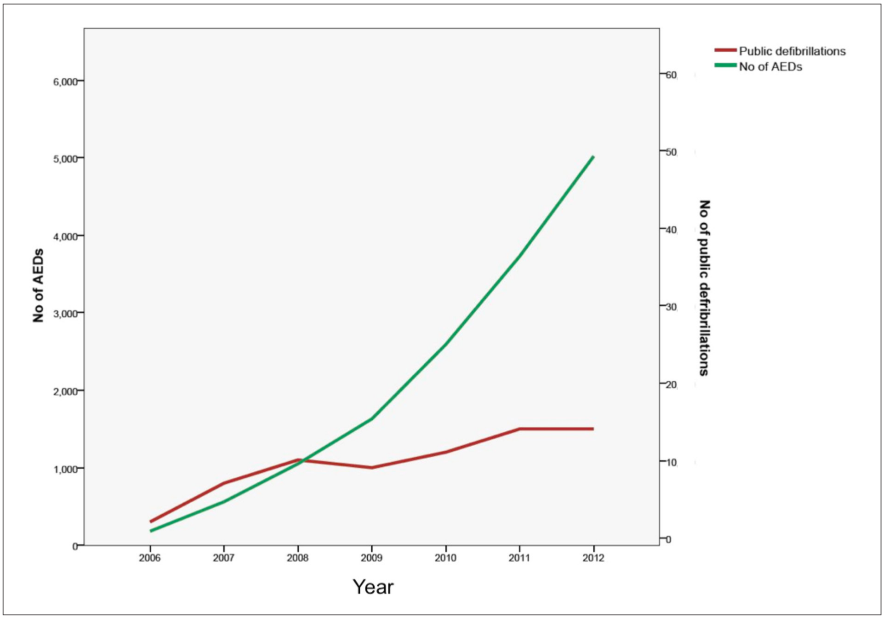


Figure 11. Defibrillation by public AEDs (n) in relation to the cumulative number of Public AEDs sold in Stockholm County 2006-2012



7.4 STUDY IV

"Impact on Bystander Cardiopulmonary Resuscitation of a Mobile Phone Positioning System and Dispatch of Lay volunteers to Out-of-Hospital Cardiac Arrests. A Randomized Controlled Trial"

At the start of the study, 5989 CPR-trained volunteers had been recruited and the number increased to 9828 during the study. The MPS was triggered in 1813 cases of suspected OHCA. The flow of patients and allocation can be seen in Figure 12.

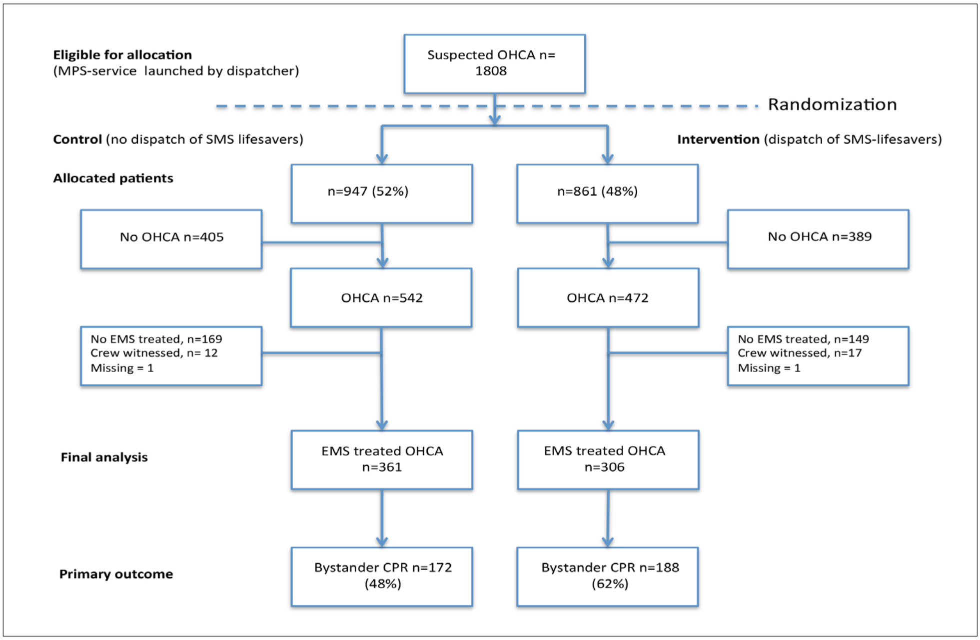
7.4.1 Main findings

The main findings are displayed in Table 6. In the final analysis of 667 EMS-treated OHCAs, 46% (n=306) were allocated to the intervention group and 54% (n=361) to the control group. Bystander CPR was more common in the intervention group (62%, n=188) compared with the control group (48%, n=172) (absolute difference, 13.9 percentage points; 95% CI 6.2 to 21.2, p <0.001).

Table 6. Primary and secondary outcomes. Study IV.

	Intervention group	Control group	Difference (95%CI)	p value
Primary outcome				
Bystander CPR	61.6%	47.8%	13.9% (6.2-21.2)	<0.001
Secondary outcome				
30-day survival	11.2%	8.6%	2.6% (-2,1 – 7.8)	ns
Return of spontaneous circulation	29.4%	29.1%	0,3% (-6,5 - 7,3)	ns
Shockable rhythm (VF/VT)	19.3%	17.3%	2.9% (-4.0 -8.0)	ns
Bystander CPR, T-CPR included	64.3%	54.7%	9.5% (2.0-16.9)	0.013

Figure 12. Flow of patients and allocation. Study IV.



8 DISCUSSION

Out-of-hospital cardiac arrest is major health challenge affecting millions of patients Prompt initiation of CPR and rapid defibrillation have repeatedly been shown to increase survival[189], but convincing evidence from other measures is scarce. Long time intervals to the arrival of medical professionals have historically been a major obstacle to increased survival. It is therefore natural to involve the laypersons closest to the patient as a part of initial treatment strategies.

8.1 CAN SURVIVAL INCREASE WITH THE CURRENT DEFINITION AND PRACTICE IN PAD?

The benefit of PAD in residential settings has been disappointing. The home AED[190]study and experiences from other studies such as the PAD-trial[191] have led to the assumption that lay-operated public AEDs should only be placed in public locations and that only OHCAs occurring in the public are available for PAD interventions[192].

The type of public location also seems to matter. In a study by Becker et al. it was found that out of 7185 OHCAs, 16 % occurred in public. Aggregations of OHCAs were found at typical high-incidence sites such as airports, transportation hubs, sport facilities and large shopping malls. The proportions of patients judged to be available for PAD intervention and the characteristics of high-incidence sites are relatively consistent, as confirmed in other studies[193,194].

Present guidelines state that AEDs should be placed in locations with relatively high rates of OHCAs. The American Heart Association (AHA) recommends placement of AEDs in places were one OHCA is likely to occur every fifth year[195]. The European Resuscitation Council promotes a more narrow interpretation, with the placement of AEDs in places with a risk of one OHCA occurring every second year[196]. In a study from Gothenburg, Engdahl and co-workers found that among 2194 OHCAs, 65 % occurred at home and 17 % of all arrests were judged as suitable for PAD, but only 2.5% (n=54) occurred at high-incidence sites with a probability of one OHCA occurring every fifth year[197].

In *Study I*, we explored the proportion and characteristics of all OHCAs occurring outside home in Sweden during a 17-year period. We concluded that at most a quarter of all OHCAs could be subjects for PAD intervention according to the current definitions. In addition, most of these cases did not occur at high-incidence sites. As survival in cases of OHCA is low, excluding patients at home and including only OHCAs occurring at high-incidence sites will probably have a limited effect on overall survival, due to the size of the total number of OHCAs.

In *Study III,* the impact of different defibrillation strategies on survival in patients available for PAD was evaluated. A total number of 135 traditional high-incidence sites were selected for implementation of a PAD programme. In a seven-year period there were 74 OHCA cases defibrillated by a public AED before arrival of dispatched units. Among these cases there were 51 survivors (71%). Although highly successful in this selected population, the public AEDs were used in only 1.1% of all EMS-treated arrests (74/6532) and in 16% of patients defined as subjects for PAD. However, with survival rates in Stockholm of around 10% in all-cause OHCA, the number of survivors that were defibrillated with a public AED is not that small, accounting for about 5–10% of all survivors. Although not a lion part of the total number of EMS treated OHCAs the absolute number of patients surviving, in comparison with other lifesaving measures in society, is not insignificant.

8.2 DECREASING INCIDENCE IN SHOCKABLE RHYTHMS, IS IT A PROBLEM?

Several reports have confirmed a nearly 50% reduction in VF incidence since the mid 1980s[198]. Current incidence rates average 20 to 25% for all OHCAs[199]. With VF being the strongest predicator of survival, this is alarming. Several explanations have been proposed including improved primary and secondary prevention of cardiac disease and changing demographics[200,201]. The results of *Study I* were in line with these observations. A reduction in VF was seen in all patients, from 46 to 42% (p for trend <0.001) and also in the subgroups of witnessed and un-witnessed cases. It should be recognized that the EMS response time also increased during this period. The implications of the reduction seen in VF incidence as regards PAD are uncertain. It is clear that time intervals have to be decreased in all patients if more are to be found in VF. However, the results of *Study III* imply that the majority of people suffering a witnessed arrest in a public location (and where an AED is applied within the first few minutes) can be defibrillated, producing survival rates as high as over 70%. This is in line with what others have found and probably reflects the short time intervals from arrest to rhythm analysis, as well as the characteristics of these patients. Unfortunately, objective information about time to defibrillation was not available in *Study III* but one can assume it was short. In a study from Denmark in which a nationwide PAD programme was evaluated, survival was 69% in OHCA cases that were shocked with a public AED[202].

Weisfeldt et al. compared the initial rhythm of OHCA victims in public versus at home and found that 79% of OHCA cases in public in whom an AED was attached had VF/VT. In cases receiving bystander CPR but no AED application the proportion was 60%. In OHCAs located at home the proportion of patients found in VF was about half of that found in cases in public. It thus seems as though OHCAs in public locations may not be affected by the decline in VF/VT as much as those at home. One can speculate that people suffering arrest in public locations are healthier, with less co- morbidity. This may reflect “hearts too good to die”[203], but nevertheless the majority of all patients are at home and often present with non-shockable rhythms and these patients must be reached earlier.

8.3 CAN BYSTANDERS BE LOCATED AND DISPATCHED TO SUSPECTED OHCA BEFORE ARRIVAL OF THE EMS?

Standard emergency medical services have historically been the sole providers of emergency care and treatment of OHCAs. After successful implementation of first responder programmes[204] it was recognized that people other than traditional medical responders are able to offer treatment in cases of OHCA. Lay responders may have the potential to have a great impact on survival, since they can respond within the first few minutes if nearby. In *Study III*, more than two-thirds survived when immediate actions were taken with defibrillation and CPR in cases of witnessed OHCA compared with one third if EMS or first responders performed defibrillation.

The importance of rapid responses by lay bystanders has repeatedly been proven[205,206]. However, low bystander CPR rates and seldom-used public AEDs are still major obstacles to increased survival.

With the aim of investigating new ways in logistics, and in order to locate and dispatch lay volunteers to suspected OHCAs within minutes, the SMS-lifesaver project was started. Mobile phone technology makes it possible to geographically locate mobile phone users. In *Study II* a mobile phone service was developed and CPR-trained lay volunteers (SMS-lifesavers) were recruited and dispatched to suspected OHCAs if present within a 500-meter distance. In 92 suspected OHCAs, one or more SMS- lifesaver(s) arrived prior to the ambulance in 45% of cases. In 17% of all EMS-treated OHCAs the SMS-lifesaver was the first to perform bystander CPR. From these results we concluded that it is feasible to use this technology to dispatch lay responders to OHCAs before ambulance arrival.

8.4 HOW CAN BYSTANDER CPR BE INCREASED AND IS IT BENEFICIAL FOR SURVIVAL?

Bystander CPR is often used for comparison of different areas. A bystander is by definition not a part of the alarm chain and is not dispatched by any means[207]. Several studies have revealed an increase in bystander CPR during the last decade associated with increased survival[208,209].

It is questionable if the increase in bystander CPR represents an actual increase in bystanders willing to perform CPR, or a result of changes in EMS reporting and logistics. In Sweden, the proportion of CPRs carried out by bystanders has increased from 45% to 70% during the last ten years, with a marked increase in 2005. At the same time, telephone-assisted CPR was introduced nationwide[210]. It is reasonable to believe that some of the increase is due to telephone-assisted CPR. Poor quality of telephone-assisted CPR has been shown in manikin studies[211,212]. It is therefore questionable if telephone-assisted CPR equals CPR performed by a trained bystander. In addition to this, dispatch of first responders such as the police and fire services has been implemented. In a significant proportion of cases the EMS personnel responsible for reporting data arrive after the first responders[213]. In these cases it may be difficult to differentiate if first responders performed bystander CPR or if a “true” bystander initially carried it out.

In *Study IV* the proportion of bystander CPR before arrival of first responders or EMS was 48% in cases allocated to the control group, thus reflecting the “true” bystander CPR rate. In the cases allocated to the intervention group, the proportion of OHCA cases receiving bystander CPR before arrival of the EMS or first responders was 62% (difference 13.9 %; 95% CI 6.2–21.2). In a recent publication from Denmark, Wissenberg and colleagues reported an increase in bystander CPR from 21% to 45% over a period of 9 years as a result of a massive national CPR-promoting initiative at several levels of society[214]. The increase in bystander CPR was found to be associated with a concurrent increase in survival from 3.5% to 10.8%. Increasing bystander CPR rates of this magnitude are usually the result of a demanding workload where mass education of lay people and a change of attitudes take several years to accomplish and may demand a large amount of resources[215].

In *Study II* and *Study IV* a novel strategy was successfully used where designated and motivated lay volunteers signed up to use their skills. We believe that increasing CPR rates of the magnitude observed, from a relatively high baseline in a few years and taking modest resources into account will have a profound impact on how CPR training among the public is best targeted and used.

In *Study II* the outcome variable was arrival of SMS-lifesaver before ambulance. *Study II* was a pilot study with the aim of evaluating technical implementation and feasibility. The ambulance service is usually the only responder in cases of medical emergency. However, in Stockholm a first responder system was running and fire and police services arrived before the ambulance in about 40% of the cases[216]. This probably explains the relatively low rate of 17% bystander CPR by SMS-lifesavers in *Study II*.

In *Study IV* the surrogate variable of bystander CPR before arrival of dispatched units was selected as primary outcome. The reason for not selecting the “harder” outcome of survival was practical, when such a study would demand thousands of patients.

CPR is a cornerstone sudden cardiac arrest treatment and there is overwhelming indirect evidence of the value of CPR both from animal and epidemiological studies[217,218,219,220]. Bystander CPR is often considered to be the backbone of treatment in cases of OHCA and millions of people are trained in CPR every year worldwide. However, the effect of bystander CPR per se has been questioned[221]. There are other factors associated with bystander CPR that can also affect survival such as witness status, location and the fact that persons who have undergone CPR training can recognize symptoms earlier and leave correct information to dispatchers. No randomized controlled trial has been performed to investigate this matter.

8.5 TRAINED OR UNTRAINED IN CPR, DOES IT MATTER?

If bystander CPR is considered to be an important factor as regards improved outcome in cases of OHCA, it is reasonable to believe that the quality of CPR would have an impact on outcome as well. It is also reasonable to assume that bystander CPR carried out by healthcare professionals would be of better quality and bystander CPR by medical professionals has proven to be associated with increased survival compared with that performed by other lay bystanders[222,223]. However, even when EMS personnel deliver CPR the quality may be far from optimal, with substantial hands-off time and chest compression that is too shallow[224,225]. Although difficult to assess, one may assume that healthcare personnel find it easier to identify a cardiac arrest and may therefore initiate CPR and call for help more rapidly.

In *Studies II* and *IV* lay volunteers signed up for the SMS-lifesaver service. Registration was web-based and the volunteers stated that they had had previous CPR training. No controls or monitoring of CPR quality were carried out during the studies. Instead, lay volunteers were offered refresher courses and their expenses were paid.

Clearly, it would have been valuable to measure CPR quality among the lay volunteers in the project. The question remains if the level of CPR training in lay responders can affect outcome. One might assume that lay responders that voluntarily sign up for a service like SMS-lifesavers are committed and well trained and therefore can perform better CPR than the occasional bystander.

8.6 IS IT ETHICAL TO DISPATCH LAY RESPONDERS TO THE HOMES OF PATIENTS WITH SUSPECTED OHCAS?

In planning the SMS-lifesaver project, the initial intent was to use the service in cases of OHCA outside home. Security officers at SALSA-PAD sites were equipped with mobile phones and were connected to the SMS-lifesaver service. In addition, about seventy taxis were also connected to the service. Because of the low event rate and the recognition that most OHCAs take place at home it was concluded that OHCAs at home must be included if survival were to be affected.

Both the project management and others raised some concerns before the start of the project. Were there risks to patients and lay volunteers? How should the interaction between EMS personnel and first responders be handled? What if persons with dishonest intentions signed up for the service? Additionally, there were concerns about reactions of lay responders to stressful situations. Debriefing was available if requested and was carried out in one case. Dispatchers were instructed not to trigger the system in cases of OHCAs among those under the age of 8 and if suicide, trauma or intoxication were suspected.

Taking into account the number of people affected by OHCA annually, the high mortality rate and the fact that most patients die while waiting for treatment, it seems reasonable that the potential advantages are greater than the potential drawbacks and that treatment should be offered to those who need it most. The number of lay volunteers is impressive and there are still an increasing number of SMS-lifesavers. Evidently there is a strong commitment among the public concerning this issue. It is recognized that cultural and legal issues are different in other countries and regions and that the results may not be applicable in all settings.

8.7 IS IT SAFE TO DISPATCH LAY RESPONDERS TO THE HOMES OF PATIENTS WITH SUSPECTED OHCAs?

During *Study II* and *Study IV* there were no major events (harm or risk of harm to patients or volunteers) that came to the attention of the project managers. There were some minor events regarding communication at the scene, in particular when SMS-lifesavers were medical professionals. During the project period the number SMS-lifesavers rose to above 11 000 in Stockholm County. In more than 3500 suspected OHCAs the SMS-lifesaver system has been triggered. In relation to these numbers, the rate of adverse events is judged to be low and in relation to the potential benefit of the system and with the addition of AEDs it is reasonable to include OHCAs at home.

8.8 HOW TO REACH THE FULL POTENTIAL OF PAD?

As implied by the results of *Study I*, only a small proportion of all cases of OHCA is available for PAD according to current definitions. New strategies are needed to identify high-risk locations and to reach patients at home in order to affect total survival. New and promising methods can be used to foresee OHCAs with greater accuracy both in residential areas and in public settings. Tools like the Geographical Information System (GIS) and the use of large databases with demographic data, EMS data, and known risk factors can be used in models to identify patterns and blind spots as regards intervention and to increase accuracy in risk estimation[226,227,228]. In an article by Folke and colleagues a grid system of 100 × 100 m cells was used to identify OHCAs in residential areas. A cell with one arrest every fifth year was defined as a high-incidence area. The areas were subsequently analysed in accordance to demographic data. The model was fit to identify up to 9% of all residential OHCAs[229]. By better identifying high-risk areas interventions with AED placement and trained responses are more likely to pay off.

Historically, transported AEDs have only been possible in the context of first responders dispatched in parallel with the EMS. However, new technology also makes it possible to dispatch lay responders to collect the nearest AED and bring it to the scene of the cardiac arrest. Such logistics are currently emerging in several settings[230,231]. In Holland a system for dispatching nearby lay responders with mobile phone text messages for CPR use and AED retrieval/use to both public locations and homes of OHCA victims has been implemented. Results from 52 cases of OHCA showed that mobile phone-dispatched laypersons arrived before EMS personnel in 21 cases, they started CPR and defibrillation in 18 cases, and assisted EMS personnel in nine incidents.

A similar approach was used in *Studies II* and *IV*, but with the outcome variable of bystander CPR. As seen in the subgroup analysis of *Study IV*, the intervention of dispatching CPR-trained lay volunteers also had a significant result in cases of OHCA located at home, with a bystander CPR rate of 54% versus 41% (difference 15 percentage points, 95% CI 6–24%).

Increasing CPR in residential locations is of special interest, since their characteristics are different from those in public locations, with lower bystander CPR rates and poorer CPR quality[232]. However, by transforming “on-site” accessible AEDs to lay responder “transported” AEDs to reach cases of OHCA both in public and residential locations, efficacy would be increased. The logistics of the SMS-lifesaver system provide this opportunity. Not only can CPR-trained volunteers be dispatched to residential locations for CPR, but by integration with registers of public AEDs, the nearest AED can also be fetched[233].

As new technology emerges, the previous definition of levels of first responders may not be sufficient. AEDs in public locations that previously were available for “on-site” defibrillation can now be recruited and mobilized. In Table 7 a new proposal for the four levels of PAD is presented, recognizing the possibility that others than traditionally dispatched units can bring an AED to the scene of an arrest.

Table 7. Proposal for a new definition of different levels of PAD

Level	Label	Example	Description	Trans ported	OHCAs at home	Trained
1	Standard EMS Paramedics	Ambulance, paramedics, physician	Dispatched units	Yes	Yes	Yes
2	Traditional first-responders	Fire and police services	Dispatched units	Yes	Yes	Yes
3	Mobile lay persons	SMS-dispatched, guided by EMS dispatch centre	Committed civilians with training or untrained civilians	Yes	No/Yes	No/Yes
4	On site” lay persons with/ without training	Fire extinguisher analogy	Occasional bystander	No	No	No/Yes

8.9 CAN AED REGISTERS BE USED FOR INCREASING SURVIVAL AND EFFICACY IN PAD?

In order to increase awareness of the locations of public AEDs, several initiatives have been undertaken to create AED registries and these can be used for several purposes. In Sweden a national AED registry was launched in 2009 and it contains data on about 10 000 AEDs that are validated every sixth months[234]. Bystanders can be guided to the nearest AED via smartphone applications[235] or receive up-to-date information on where AEDs are located throughout their neighbourhood. In an unpublished analysis carried out in Stockholm we found that nearly 40% of all OHCAs took place within a 300-m distance from a public AED that was not used. In a study from Copenhagen by Hansen and co-workers, 29% of all OHCAs in public locations were within 100 m of an AED[236]. However, when the temporal circumstances were taken into account, AED coverage decreased substantially. This suggests that accessibility may be overestimated as a result of a temporal mismatch – most OHCAs occur out of office hours and the authors suggested that temporal information about AED accessibility must strongly be taken into account. This problem may partly be solved with the integration of other solutions such as AED maps[237] and mobile phone location and dispatch of lay responders. The awareness of blind spots can direct community interventions to areas with low AED coverage.

9 CONCLUSIONS

The current definition of OHCA patients that are available for public AED use includes at the most a quarter of all cases. Amongst these patients a decreasing incidence of VF was observed, which further reduces the proportion that can be treated by means of defibrillation.

The number of AEDs in public locations has increased during the last decade. They are seldom used in relation to their numbers, but when used, survival rates can be as high as 70 %.

Mobile phone technology can safely be used to locate and dispatch CPR-trained lay responders to suspected OHCAs within 500 metres and prior to EMS arrival.

Mobile phone technology and dispatch of CPR-trained lay responders to OHCAs can significantly increase bystander CPR rates both in public and residential settings.

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Out of hospital cardiac arrest outside home in Sweden, change in characteristics, outcome and availability for public access defibrillation

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Abstract

Background: A large proportion of patients who suffer from out of hospital cardiac arrest (OHCA) outside home are theoretically candidates for public access defibrillation (PAD). We describe the change in characteristics and outcome among these candidates in a 14 years perspective in Sweden.

Methods: All patients who suffered an OHCA in whom cardiopulmonary resuscitation (CPR) was attempted between 1992 and 2005 and who were included in the Swedish Cardiac Arrest Register (SCAR). We included patients in the survey if OHCA took place outside home excluding crew witnessed cases and those taken place in a nursing home.

Results: 26% of all OHCAs (10133 patients out of 38710 patients) fulfilled the inclusion criteria. Within this group, the number of patients each year varied between 530 and 896 and the median age decreased from 68 years in 1992 to 64 years in 2005 (p for trend = 0.003). The proportion of patients who received bystander CPR increased from 47% in 1992 to 58% in 2005 (p for trend < 0.0001). The proportion of patients found in ventricular fibrillation (VF) declined from 56% to 50% among witnessed cases (p for trend < 0.0001) and a significant (p < 0.0001) decline was also seen among non witnessed cases.

The median time from cardiac arrest to defibrillation among witnessed cases was 12 min in 1992 and 10 min in 2005 (p for trend = 0.029). Survival to one month among all patients increased from 8.1% to 14.0% (p for trend = 0.01). Among patients found in a shockable rhythm survival increased from 15.3% in 1992 to 27.0% in 2005 (p for trend < 0.0001).

Conclusion: In Sweden, there was a change in characteristics and outcome among patients who suffer OHCA outside home. Among these patients, bystander CPR increased, but the occurrence of VF decreased. One-month survival increased moderately overall and highly significantly among patients found in VF, even though the time to defibrillation changed only moderately.

Background

Cardiovascular disease is a common cause of death in the western world and many of these deaths occur suddenly due to out-of-hospital cardiac arrest (OHCA) [1]. Survival rates in major urban areas remain poor [2], despite the introduction of the chain-of-survival concept [3] and new in-hospital treatment strategies. The use of a community-based emergency medical service (EMS) as a single rescue force may not be sufficient to improve survival, as the time from collapse to defibrillation remains long [4]. The use of automated external defibrillators (AEDs) by non-medical personnel is adding new opportunities for shortening time intervals and several EMS systems have attempted to reorganise their strategies using the "first responder concept", which involves the activation of security guards, policemen and firemen for early defibrillation [5].

The concept of Public Access Defibrillation (PAD) postulates the widespread deployment of AEDs in heavily populated areas and high OHCA incidence sites [6]. In recent years, there has been evidence of a declining incidence of OHCAs found in shockable rhythms, making fewer patients suitable for defibrillation [7,8]. This raises questions about the rationale of implementing full-scale PAD programmes. How many of all OHCA patients are really potential subjects for PAD and have their characteristics changed? In a careful analysis of the situation in Scotland in 1991 – 1998 Pell et al found 18% of all OHCA in whom CPR was attempted to be suitable for PAD.

The overall aim of this study was to describe the patients in Sweden who suffer OHCA outside home, in whom CPR was attempted during a 14 years period. The major aim was to evaluate eventual changes among these patients in characteristics and outcome with the focus on availability for PAD.

Methods

Swedish Cardiac Arrest Register

This survey is based on data from the Swedish Cardiac Arrest Register (SCAR). The register currently covers about 70% of all Swedish OHCA patients in whom CPR is attempted and is a quality register supported by the Swedish National Board of Health and Welfare. The figure of 70% is a rough estimation. Recent information on the representativeness of all participating centers is not available. Recent quality checks in the two largest cities (Stockholm and Göteborg) indicate that between 90–95% of patients are included in the register. A survey 9 years back indicated that the register covered between 85–90% of all cases where CPR was attempted in the participating organisations. At present we estimate that about 80% of ambulance organisations participate in the register and that about 90% of OHCA patients in each participating organisation are reported to the register. About half of all participating organisations have participated each year during the time of the survey. There is no tendency including more urban services or more rural areas during the last years. Large cities (including all major cities) and sparsely populated areas are represented in the register which has a geographical distribution covering the vast majority of Sweden. The ambulance organisations that do not report to the register are not different in terms of education or guidelines. Ambulance organisations around Sweden continuously report data and this procedure includes the completion of a standard form with a detailed description of the circumstances and interventional actions for each OHCA in which CPR was performed. The procedure is described below.

Dispatch and ambulance organisation

There are about 100 ambulance organisations serving nine million inhabitants in Sweden. During the last few decades, the aim of the Swedish Board of Health and Welfare has been to equip every ambulance with a trained nurse and this has also gradually been implemented all over Sweden. Furthermore, an increasing number of ambulances now carry crew members with advanced training in anaesthesiology and cardiac life support.

All ambulances in Sweden are dispatched by one of 18 different dispatch centres. The dispatch centres are similar throughout the country in terms of organisation and emergency call processing. The dispatcher uses a standardised protocol with a specific questionnaire for the identified emergency. As soon as a suspected cardiac arrest is identified, the ambulance is dispatched and the emergency call proceeds. The organisation of the dispatch centres and emergency call processing has not been subject to change over the study period.

Study design

All patients included in the SCAR suffering an OHCA in whom CPR was attempted between 1992 and 2005 were included in the study. Patients were judged to be theoretically available for PAD if the cardiac arrest took place outside the home or outside a nursing home. Bystander-witnessed and non-witnessed cases were included. Crew-witnessed cases were excluded.

For each OHCA, the ambulance crew filled in a detailed form relating to the circumstances of the arrest. The form contains information about patient characteristics such as age, gender and place of arrest (crew witnessed, at home, in a public place, in an ambulance, at work) and presumed cause of the cardiac arrest. The classification of the probable cause of the cardiac arrest was made by the ambulance crew based on information at the scene and bystander information. Their diagnosis was accepted for this study and no further checks were made. Furthermore, detailed information was included about crucial junctures at resuscitation, such as the time of collapse and the time of interventional measures such as the initiation of CPR, defibrillation, drug administration and intubation. The type of initial rhythm was registered and defined as VF (this includes pulseless ventricular tachycardia) or asystole. The form also includes EMS-related data concerning the time of ambulance dispatch and arrival at the scene. Information was entered about bystander characteristics, such as whether or not the collapse was witnessed and whether bystander CPR was performed. The outcome of resuscitation attempts was defined as dead on ambulance arrival, dead in the emergency room, admitted to hospital and survival to one month. All the data were computerised in a database in Göteborg. The content of the form, definitions and the way data were reported to the SCAR remained unchanged during the study period.

This study was approved by the local ethics committee.

Statistical methods

Proportions are expressed as percentages and continuous variables as medians. Trend tests for associations with the time variable year of OHCA were performed using the Mann-Whitney U test for dichotomous variables and Spearman's rank correlation for continuous variables. In the evaluation of proportions Fisher's exact test was used. All p-values are two-tailed and considered significant if below 0.05.

Results

Overall there were 38710 patients suffering OHCA in whom CPR was attempted included in the register between 1992 and 2005 of whom12% had a crew witnessed OHCA, and 62% occurred either at home or in a nursing home. The overall survival to 1 month was 5.4%.

Patient characteristics and percentage of patients available for PAD

Twenty-six % of all OHCA patients fulfilled the inclusion criteria. The corresponding percentage values for the 3 largest cities in Sweden (Stockholm, Göteborg and Malmö) was 27% and for the remaining part of Sweden it was 26% (p = 0.03) The total number of patients included from 1992–2005 was 10133 with an annual inclusion rate that varied between 530 and 896 patients (Additional file 1, Table S1). The median age declined from 68 years to 64 years during the study period (p for trend = 0.003). The proportion of OHCAs of cardiac origin decreased from 72% in 1992 to 61% in 2005 (p for trend < 0.0001). No significant trend was found regarding sex distribution.

Time intervals, initial rhythm, and bystanders

The median time interval from cardiac arrest to defibrillation was 12 minutes in 1992 and 10 minutes in 2005 (p for trend = 0.029); changes were minor (Additional file 1, Table S1). The ambulance response time increased (p for trend < 0.0001) but the time between cardiac arrest and start of CPR decreased (p for trend < 0.0001) (Additional file 1 Table S1).

The proportion of patients initially found in VF was analysed for three different groups of patients: all OHCA cases, bystander-witnessed cases and non-witnessed cases.

As shown in Additional file 1, Table S2 and Figure 1, the proportion of patients found in VF decreased significantly within all three groups.

The proportion of bystander-witnessed OHCA cases did not show any significant trend during the study period. However, a marked increase from 47% to 58% (p for trend < 0.001), in the proportion of OHCAs receiving bystander CPR was observed (Additional file 1, Table S3, Figure 1).

Survival (Additional file 1, Table 1–3, Figure 1)

The proportion of patients admitted alive to hospital tended to increase during the study period (p for trend = 0.03). Survival to one month was analysed within five different groups of patients. Among all patients there was an increase in survival to 1 month (p for trend = 0.01). In the subgroup of patients found in VF there was a significant increase, from 15.3% in 1992 to 27.0% in 2005 (p < 0.0001 for trend), in one month survival. In Figure 1 is shown trend curves for changes in overall survival to 1 month, occurrence of ventricular fibrillation and bystander CPR.

Discussion

Percentage of patients available for PAD

The principal findings in this study are that about a quarter (26%) of all OHCA patients in Sweden in 1992–2005 occur outside home and are not crew witnessed and that, among these patients, there is a decreasing number of patients with VF as the first recorded rhythm despite an increasing rate of bystander CPR.

Within the study period, there were no alterations in the guidelines relating to whether or not CPR should be attempted. The conclusion is nevertheless that there was no dramatic change in the number of OHCAs that might be candidates for PAD.

In Scotland, Pell and colleagues found that 18% of all OHCAs were found to be suitable for PAD in the 1990ths. [9]. The larger percentage (26%) found in our study is explained by the wider definition, including all "theoretically" available OHCAs. Considerations based on the location of the OHCA, witnessed status or whether the OHCA was "practically" suitable for defibrillation were not taken into account in our study, whereas in the Scottish survey they excluded OHCAs on street, in train, tram

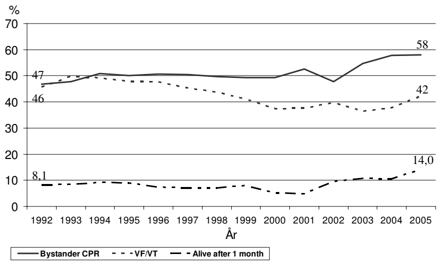

Figure 1
Trend curves for changes in survival to 1 month, bystander CPR and occurrence of ventricular fibrillation.

etc. All cases excluded in the Scottish study might not be relevant for the situation today. For example are there plans to equip major trains in Sweden with defibrillators in the near future. Furthermore, soon will some taxidrivers in Stockholm have AED in their cars which might make PAD also in streets feasible. The proportion of patients who in reality will be available for PAD might be somewhere between 18% as in the Scottish survey and 26% as in our survey

In the study from Scotland 36% of all non crew witnessed OHCAs occurred outside home which is similar to our findings (34%). However, the proportion of patients found in a shockable rhythm appeared to be much higher in the Scottish survey as compared with our survey.

Epidemiology

We estimate that the Swedish Out of Hospital Cardiac Arrest Register includes about 70% of all OHCA:s in whom CPR was attempted. This is due to a combination of limited number of ambulance organisations, which reported to the register and a limited number of reports from the participating organisations.

Our estimate indicate that there are about 45 OHCAs in whom CPR is attempted per 100.000 inhabitants and year. It is important to stress that these cases cover only a minority of cardiovascular deaths in Sweden (in a large proportion CPR is never started). According to statistics from the Swedish National Board of Health and Welfare there was a total number of 26132 persons who died from cardiac disease in Sweden in 2005 (289/100 000 inhabitants and year). About two thirds (n = 17709) of these deaths were due to ischemic heart disease (ICD-10, I20–I25) and one third was due to other forms of heart disease (ICD-10, I30–I52).

Patient characteristics

We found a trend towards a decreasing median age, with a drop from 68 to 64 years during the study period. This in not line with what others have found. From a study conducted in Seattle between 1977 and 2001, Rea and colleagues reported an increase in the mean age among EMS-treated cardiac arrests from 64 to 68 years of age [10]. It is only possible to speculate that, among the victims of sudden death included in our study, there is a higher percentage of OHCAs with undiagnosed cardiac disease, physically capable and healthy enough to be out in public places. These cases perhaps conform to a higher extent with "hearts too good to die" [11]. On the other hand, Kuisma and co-workers found that OHCA of non-cardiac origin is more likely to take place among the younger members of the population and is secondary to pulmonary disease, internal bleeding, suicide, trauma and drug intoxication [12]. These findings could suggest that the drop in the mean age of victims of OHCAs in our survey could to some extent be explained by the concurrent increase in OHCAs of non-cardiac aetiology that was also observed. The data relating to the aetiology of the OHCAs in our study must be interpreted carefully, as they are based on the clinical judgement of the EMS personnel and not on autopsies or clinical investigations.

Bystanders

We found that bystander CPR increased from 47% to 57%. These results are promising and could be the result of a greater knowledge of CPR among the general population. During the last few decades, large-scale educational efforts have been made to spread a knowledge of CPR among the Swedish population [13] and the increase in bystander CPR may be a result of these efforts. During the study period, telephone-assisted CPR was implemented in 1997. These measures may also have contributed to the overall increase in bystander CPR

Initial rhythm

A major finding is the declining incidence of VF as the first recorded rhythm also in this cohort. The decline applies to all the patients in the study, as well as to the subgroups of bystander-witnessed and non-witnessed cases. These findings are confirmed by data reported by others and this observation has been made in both Europe and the United States [14,15]. However, it is the first time that the decline is reported among theoretical candidates for PAD during such a long follow up. A declining percentage of OHCA patients with VF as the first recorded rhythm has been observed, despite efforts to reduce call-to-shock time through PAD programmes, first responder systems and increased bystander action. Different theories have been launched to explain the declining incidence of VF. Bunch and colleagues [16] reported a decline in the incidence of VF attributed to ischemic heart disease, which suggests that successful secondary and primary prevention against ischemic heart disease are contributing to a lower incidence of OHCAs found in VF. It has been suggested that the increasing use of reperfusion therapy, smoking cessation, cardiac surgery, anti-arrhythmic and anti-thrombotic drugs, as well as implantable cardioverter defibrillators (ICD) and lipid lowering drugs, is having an impact on sudden cardiac death, since ischemic heart disease is the main cause of life-threatening arrhythmias. The widespread use of beta-blocking agents as a cornerstone in the treatment of ischemic heart disease has been proposed as an important promoter of these changes [17]. The explanations given above can also help us to understand our data. According to statistics from the Swedish National Board of Health and Welfare, the incidence, morbidity and mortality due to ischemic heart disease are decreasing sharply in Sweden and in the rest of the western world [18,19]. The call-to-shock interval has remained rather constant throughout the study period, and it can therefore hardly be used to explain these changes.

The drop in VF incidence in our material can also be partly explained by the concomitant decrease in the number of OHCAs judged to be of cardiac origin, as patients with other etiology are more likely to present as asystole or PEA. The decrease in the percentage of OHCAs judged to be of cardiac origin is probably due to the decrease in morbidity from cardiovascular disease. Data from the Swedish Death Registry state that the number of deaths from suicide, drowning, intoxication and accidents remained unchanged or decreased during the study period, suggesting that an increased number of OHCA patients suffer from "multi-system organ failure" or other chronic illnesses. [20].

Survival

Bystander CPR and VF as the first recorded rhythm are two factors strongly associated with improved survival after OHCA [21]. One-month survival among victims of OHCAs increased particularly among patients found in ventricular fibrillation. This increase could be a result of improved post-resuscitation care following the introduction of new treatments such as mild hypothermia and early revascularisation, as well as pre-hospital improvements including an increase in bystander CPR. Improvements in pre-hospital and in-hospital factors can help to explain why overall survival to one month increased, despite the drop in the incidence of ventricular fibrillation.

Our findings in the context of PAD and first responder programmes

The alarming evidence about a decline in the incidence of VF found among patients who suffer OHCA outside home has been confirmed by several other studies which did not particularly focus on OHCA outside home. In the light of these findings, PAD and public access programmes are likely to become less successful if this trend continues. On the other hand, shortening time intervals using first responder programmes could be the way to reverse this trend. This raises the question of the cost effectiveness of PAD programmes which has previously been debated [22]. There is good evidence to suggest that the structured, wide deployment of AEDs with trained laymen alerted by a central dispatch centre system could improve survival rates in selected populations [23]. A recent Austrian PAD study makes it clear that unstructured and "over the counter" PAD programs are probably less effective [24]. However, the question of whether it is reasonable to exclude all OHCAs that take place in non-public places can also be discussed. By doing this, total survival rates after OHCA can hardly be affected. Only survival in absolute numbers will be affected.

In spite of this, sudden cardiac death is a major health problem and one of the main causes of death. Tremendous efforts are being made in the in-hospital world to take care of patients and, as a result, most patients die outside hospital. While PAD programmes only appear to affect about 15–25% of all OHCAs, substantial progress has to be made if overall survival rates are to be affected. Perhaps we should concentrate on numbers of survivors instead of survival rates? The limitations of not reaching the majority of OHCAs that do not take place in public places are included in the PAD concept. The time intervals within the standard EMS system are still too long. New techniques could perhaps lead to the more rapid activation of first responders, making it possible to reach OHCAs earlier. Further knowledge about the changing incidence and treatment of non-shockable rhythms also needs to be generated. This will perhaps be the main challenge in the future.

Limitations

1. There is some degree of uncertainty with regard to representativeness of the register.

2. There is missing information with regard to all variables in the register.

3. The register is not detailed enough to fully cover the "true" availability for PAD.

Conclusion

In Sweden, 26% of all OHCAs in whom CPR was started occur outside home but are not crew witnessed and might theoretically be regarded as candidates for PAD. Among these patients, bystander CPR has increased, but the percentage found in ventricular fibrillation has decreased. Time to defibrillation has remained almost unchanged. By reducing the delay in the chain of survival, the decrease in ventricular fibrillation could be reversed. Widespread

PAD programmes can play a crucial role in this health care area, although new ways to alert first responders and reach OHCA victims may be necessary if total survival rates are to be affected.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MR has contributed by analysing all the data and written the manuscript. JH has contributed by preparing the design of the manuscript including tables and figures and has also critically evaluated the text and is responsible for all figures in the tables. JaH has participated in the design of the manuscript and critically evaluated the text of the manuscript. MR has participated in the design of the manuscript and critically evaluated the text of the manuscript. LS has participated in the design of the manuscript and critically evaluated the text of the manuscript. All authors read and approved the final manuscript.

Additional material

Additional file 1

Table S1, S2 and S3*. Table S1 – Proportion of patients available for PAD and their characteristics and outcome. Table S2 – Occurrence of ventricular fibrillation, delay to defibrillation and outcome in relation to ventricular fibrillation. Table S3 – Total witnessed status, bystander CPR and outcome in relation to witnessed status.*
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Clinical Paper

Mobile phone technology identifies and recruits trained citizens to perform CPR on out-of-hospital cardiac arrest victims prior to ambulance arrival☆

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ABSTRACT

Aim: In a two-parted study, evaluate a new concept were mobile phone technology is used to dispatch lay responders to nearby out-of-hospital cardiac arrests (OHCAs).

Methods: Mobile phone positioning systems (MPS) can geographically locate selected mobile phone users at any given moment. A mobile phone service using MPS was developed and named Mobile Life Saver (MLS). *Simulation study*: 25 volunteers named mobile responders (MRs) were connected to MLS. Ambulance time intervals from 22 consecutive OHCAs in 2005 were used as controls. The MRs randomly moved in Stockholm city centre and were dispatched to simulated OHCAs (identical to controls) if they were within a 350 m distance. *Real life study*: during 25 weeks 1271–1801 MRs trained in CPR were connected to MLS. MLS was activated at the dispatch centre in parallel with ambulance dispatch when an OHCA was suspected. The MRs were dispatched if they were within 500 m from the suspected OHCA.

Results: Simulation study: mean response time for the MRs compared to historical ambulance time intervals was reduced by 2 min 20 s (44%), $p < 0.001$, (95% CI, 1 min 5 s – 3 min 35 s). The MRs reached the simulated OHCA prior to the historical control in 72% of cases. *Real life study*: the MLS was triggered 92 times. In 45% of all suspected and in 56% of all true OHCAs the MRs arrived prior to ambulance. CPR was performed by MRs in 17% of all true OHCAs and in 30% of all true OHCAs if MRs arrived prior to ambulance.

Conclusion: Mobile phone technology can be used to identify and recruit nearby CPR-trained citizens to OHCAs for bystander CPR prior to ambulance arrival.

1. Introduction

Survival from out-of-hospital cardiac arrest (OHCA) is generally low, about 5–10%, with the exception of a few controlled settings (casinos, airports and some cities).[1,2] The poor prognosis of OHCA is mainly explained by long time intervals between cardiac arrest, cardiopulmonary resuscitation (CPR) and defibrillation.[3] To increase bystander actions and to decrease time to defibrillation substantial resources have been put into CPR educational campaigns and in recent years into the spread of automated external defibrillators (AEDs) in public venues.[4] Still, the vast majority of the public with CPR training will never use their skills in real life and most public AEDs will never be deployed.[5] Mobile phone technology offers the possibility to locate single mobile phone users at any given moment. If designated lay responders immediately can be identified and recruited to the scene of nearby suspected OHCAs bystander CPR, CPR quality and the use of public access AED might be increased.

The aim of this paper is to describe how mobile phone technology and mobile positioning systems (MPS) can be used to identify lay responders and recruit them to the scene of nearby OHCAs prior to ambulance [emergency medical responders (EMS)] arrival. This paper describes the PILOT-part (focus on technological potentiality and time cuts in cardiac arrest treatment) of the RUMBA (Response to Urgent Mobile Message for Bystander Activation)-project. The RUMBA-project has an overall purpose of increasing survival after OHCA in Stockholm by the activation of CPR-trained citizens and mobilisation of public defibrillators.

2. Methods

2.1. Mobile positioning system (MPS)

A mobile phone positioning system (MPS) uses the infrastructure of a mobile phone network to obtain the geographical position of selected mobile phones at any given moment. In urban areas the accuracy varies between 0 and 75 m. In Sweden, where this study

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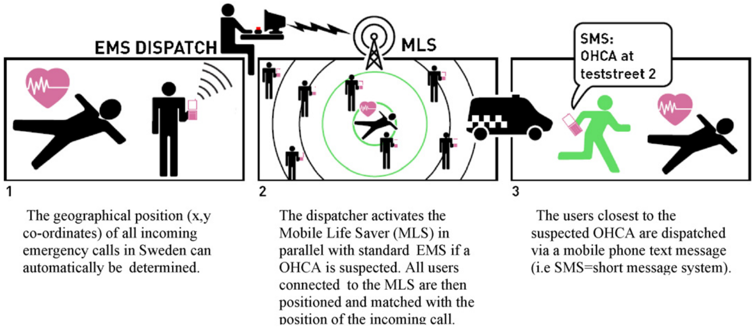

Fig. 1. Logistics and infrastructure of the Mobile Life Saver Service.

was carried out, all major mobile phone service providers use GSM (Global System for Mobile Communications) networks.

2.2. Mobile phone positioning and dispatching of lay responders

Tailored mobile phone services that use MPS to locate selected mobile phone users can be developed for different purposes. A computer-based application for mobile phone positioning and dispatch of lay responders was developed by LEKAB Communication Systems and is referred to as the *Mobile Lifesaver Service* (MLS). All participants connected to the MLS were called *Mobile Responders* (MRs). The MLS acts as an interface between the emergency medical service (EMS) data system and the MPS. The MLS handles the localisation and dispatching of MRs based on the data present in the EMS data system (Fig. 1). The location of all incoming calls to all dispatch centres in Sweden is determined. When the dispatcher receives an emergency call from a witness of a suspected OHCA the dispatcher activates the MLS in parallel with standard EMS. When the MLS is activated it uses the MPS to compare the current geographical position of all MRs connected to the MLS with the position of the incoming emergency call of the suspected cardiac arrest. If one or more MRs is present within a radius of 500 m (optional) from the suspected arrest the MRs receives a cardiac arrest alert with a computer generated phone call and a text message (i.e. SMS = short message system) with information about the place of the suspected cardiac arrest (Fig. 1). Additional information can, if needed, be sent to the MRs.

2.3. Study design

The study was carried out in two separate phases, a simulation study and a real life study. The simulation study evaluated the technology and potentiality in decreasing time intervals for mobile phone dispatched lay responder to simulated OHCAs compared to standard EMS. The real life study was a large scale study carried out in a real life environment with >1500 MRs and suspected OHCAs.

2.4. Simulation study

During one day in April 2008, 25 volunteers acting like MRs, each carrying a mobile phone connected to the MLS, received specific instructions to move randomly in an area of 2.3 sq km in downtown Stockholm (Fig. 2). The MRs received simulated cardiac arrest alarms as dialled up voice messages and SMS messages with information that was identical to the information presented by the EMS dispatchers (in terms of place of arrest, EMS time intervals and information available at the time of dispatch) for 22 consecutive real life cardiac arrests from 2005. These 22 cases that were used as historical controls had all taken place in public places in the city centre of Stockholm, Sweden and were all bystander witnessed. The MRs received alarms only if they happened to be within a distance of 350 m from the place of the simulated arrest. The assumption was made that this was the distance the MRs could walk in brisk pace in 3 min. Observers were placed at the same location as the historical arrests and the time from dispatching to arrival on scene for the MRs was measured. The time intervals for each alarm were then matched and compared to the EMS time intervals for the corresponding historical control. Watches of the observers were synchronised using atomic clock references.

2.5. Real life study

The real life study was carried out from June 2, 2010 until November 23, 2010. In the beginning of the study period, 1261 volunteers had signed up and been registered as MRs and were connected to the MLS. This number increased to 1801 at the end of the study. The MRs were recruited through mass media campaigns including advertisements in newspapers and at web sites. A project web site was launched for registration of participants and for information about the RUMBA project.[6] The only condition for registration was that the MRs had undergone CPR training.

The dispatchers at the EMS centre had been given instructions to activate the MLS in parallel with standard EMS if a witnessed non-traumatic cardiac arrest was suspected. The activation of the MLS was integrated into the EMS data system in order not to delay regular EMS dispatch. All suspected OHCAs where the MLS was triggered were included regardless of location or cause of the suspected OHCA. The MRs received cardiac arrest alarm calls and SMS messages if they were closer than 500 m from a suspected arrest. The dispatcher at the EMS centre had the possibility to send additional information to the MRs (i.e. door codes) via SMS.

The study area had a size of approximately 26 sq km and included the most densely populated areas of the Stockholm city area (Fig. 2) with a total number of 612,784 inhabitants.[7] On average each MR covered a circular area with a radius of 83 m in the beginning of the study period (decreasing to 68 m in the end of the study period due to an increase in the number of MRs).

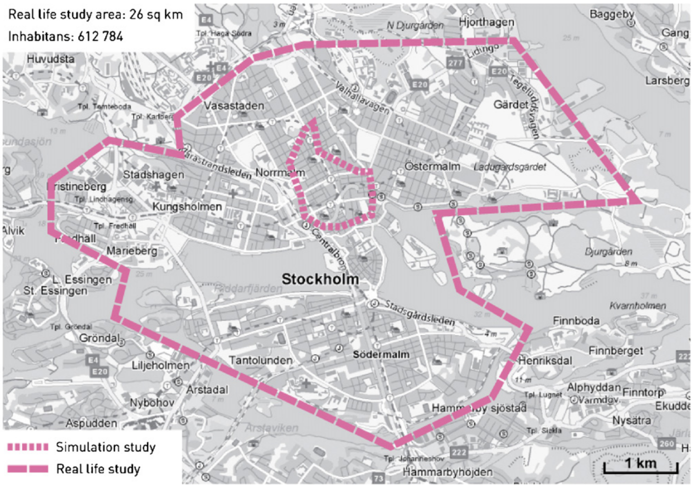

Fig. 2. Map of urban Stockholm with suspected OHCA.

2.6. *Data collection and definitions*

Data about the suspected cardiac arrests cases such as EMS time intervals, location and resuscitation attempts were obtained from the EMS data system and EMS reports. Suspected OHCA was regarded to be true cardiac arrests if any resuscitation attempts were performed by EMS personnel (i.e. administration of vasoactive drugs, assisted breathing, chest compression or defibrillation). All MRs that responded to cardiac arrest alarms underwent a questionnaire. The MRs were accounted to be arriving prior to EMS if the MR was first on scene and there was no visual contact with the ambulance at the time of MR arrival. The MRs were accounted for performing CPR if they made chest compressions, rescue breaths or both.

2.7. *Ethics, integrity and safety*

The study was approved by the local ethical committee in Stockholm, Sweden. All MRs agreed upon registration to not utter any details about the suspected cardiac arrest alarms that could lead to identification of patients. The MRs had to agree to be geographically positioned before receiving alarms of suspected OHCAs. The MRs were able to at any time erase their user information at the project website. Address information sent to the MRs were sometimes specific about floor number, name on the door and door codes. However, specific personal information such as the full name of the patient or birth of date was not sent. Data was stored in accordance to Swedish legislation and owned by the project exclusively.

2.8. *Statistics*

Data are presented as means ± standard deviation (SD), means with 95% confidence interval (CI) or proportions. Difference in time intervals was analysed for significance with the dependent samples *t*-test. The Kolmogorow–Smirnow test revealed normal distribution of data.

3. Results

3.1. *Simulation study*

The mobile phone dispatched MRs reached the location for the cardiac arrest before the EMS in 72% ($n = 17$) of the cases. One cardiac arrest was not found by the MRs due to insufficient address information. The mean difference in response time between the historical controls and the MRs was 2 min 20 s, $p > 0.001$, (95% CI: 1 min 5 s – 3 min 35 s). The median response time from cardiac arrest to arrival at the scene of OHCA for the mobile phone dispatched MRs were reduced by 56% compared to historical EMS time intervals, 5 min 44 s to 2 min 30 s (Table 1).

The mean time for the geographical positioning of the mobile phones ($n = 22$) was 20 s (SD ± 13). There was furthermore a delay of 22 s (SD ± 13 s) from when the dialled up alarm call was made and until it was confirmed by the mobile phone user. Thus, within the MLS there was a delay from when the application was triggered to the time when the positioning of all the participating mobile phones was made. The total dispatch time for the MRs varied between 34 s to 3 min and 32 s (mean of 1 min 27 s, SD ± 45 s).

Table 1
Main results, simulation study.

First on scene	%		
MRs first	72		
EMS first/same time as MRs	28		
Response times (min:sec)			
N = 22	EMS response time	Mobile responder response time	Time difference
Mean	5:18	2:58[a]	2:20 ($p < 0.001$)
Median	5:44	2:30	3:14
Std. Deviation	1:35	2:02	2:45

[a] In one case the MR could not find the correct address due to insufficient dispatch information.

Table 2
Main results, real life study.

Number of cases = 92	% (*n*)
First on scene	
MRs first	45 (41)
EMS first/same time as MRs	55 (51)
Proportion of cases with MRs recruited to the scene	99 (91/92)
Mean distance from suspected OHCA for MRs reaching the scene before the EMS	251 m
MRs within 500 m from suspected OHCA on average[a]	
1–3	5 (5)
4–9	37 (34)
>10	58 (52)
Suspected OHCA between 08 and 20	72 (66)
Location of suspected OHCA	
At home	64 (58)
Outside home	36 (33)
Diagnosis of suspected OHCA[a]	
Confirmed OHCA	40 (36)
Other cause/unclear	60 (54)

[a] In one case no MRs were positioned or dispatched; calculations based on the remaining 91 cases. 2 cases with missing data regarding diagnosis, calculation based on the remaining 90 cases.

3.2. Real life study

During the 25 week long study period a total of 92 cases of suspected cardiac arrests resulted in activation of the MLS (Table 2). In 45% of all cases one or more MRs reached the location of the suspected OHCA prior to EMS arrival. In 91 out of the 92 cases (99%), one or more MRs was dispatched and actually reached the location of the suspected OHCA. Mean EMS response time for the 92 suspected OHCAs was 7 min and 8 s.

On average, 12 MRs were present within a distance of 500 m in each case of suspected OHCA. The mean distance of the dispatched MRs to the suspected OHCA at the time of dispatch was 251 m. The mean time from the incoming emergency call to EMS dispatch was 3 min and 51 s. The mean time from arrival of the emergency call and the activation of the MLS was 4 min and 3 s. accordingly; there was a 12 s delay from EMS dispatch to when the positioning of the MRs was started.

The majority of all cases of suspected OHCA took place between 08 and 20 h (72%). 64% of the cases occurred at home and 36% outside home. In 90 out of 92 cases information about the final diagnosis could be retrieved. 40% of all calls were judged to be true cardiac arrests (i.e. resuscitation attempts were made by the EMS) and amongst these cases one or more MRs reached the place of the arrest prior to the EMS in 56% ($n = 20$). In the group of true OHCA cases where an MR was first on scene, CPR was performed by MRs in 30% ($n = 6$). In total, CPR was performed by MRs in 17% of all true cardiac arrests (Fig. 3). There were no significant adverse events reported by the MRs or by EMS personnel during the study period.

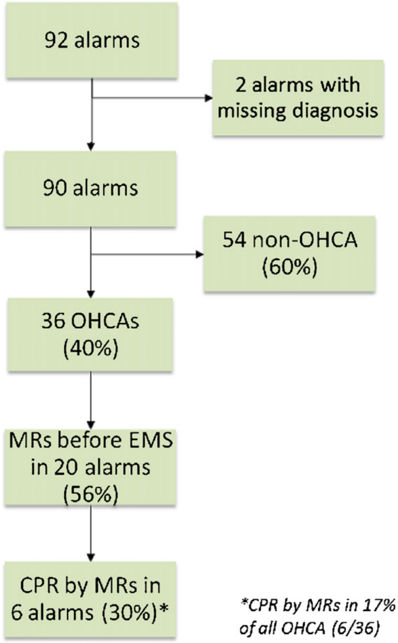

Fig. 3. Resuscitation efforts by Mobile Responders.

4. Discussion

To our knowledge, this paper is the first to present a method where mobile phone technology and mobile positioning system have been used to identify and recruit CPR-trained citizens to the scene of suspected OHCA prior to ambulance arrival. Additionally, we have demonstrated that these CPR-trained lay responders performed CPR in a significant proportion of the OHCAs cases.

4.1. Simulation study

Mobile positioning systems is used in different commercial services. We hypothesized that this technology could be used in the context of OHCA. Although experimental, the result of the first part of the study indicates that the technology may be suitable for recruiting lay responders to OHCA before ambulance arrival. Despite that mean EMS response time was relatively short (5 min 44 s), lay responders were recruited to the simulated arrests prior to historical EMS controls in the majority of cases (72%) and response times were significantly shorter for the MRs. However, some methodological considerations are required. First, MRs connected to the MLS were motivated and informed about the project. Second, this study was performed during only one day. This probably results in a higher state of awareness amongst the participants than could be expected in real life. Moreover, our survey took place in downtown Stockholm, an area that the majority of the participants were familiar with. These aspects make the response times shorter than one can expect in a real life situation. Nevertheless, the simulation study confirmed the functionality of the system and indicated the potentiality of the use of MPS in recruitment of lay responders to the scene of OHCAs within minutes. All this encouraged us to further evaluate its potentiality in a real life setting.

4.2. Real life study

In the second phase of our study we implemented the MPS technology into the EMS data system and managed to demonstrate its functionality in real life. Out of the 92 cases, there was only one case in where no mobile responder was dispatched. In 45% of all cases one or more MRs reached the location of the suspected OHCA prior to EMS arrival and in true OHCAs the proportion was even higher (56%). This, in addition to that CPR was performed by the MRs in about one third of all true OHCAs where an MRs arrived first on scene and in 17% of all true OHCAs alarms shows the potentiality of the system.

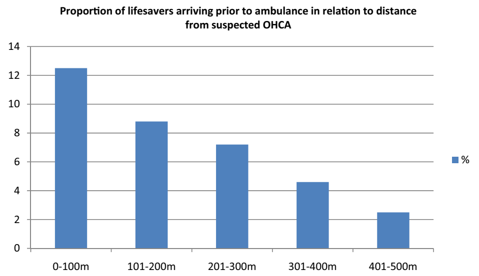

Fig. 4. Proportion of life savers arriving prior to EMS in relation to number of life savers at distance from suspected OHCA. Real life study.

In the real life study, a mean of 12 MRs were present within a distance of 500 m in each case of suspected OHCA. The chance of a MR reaching the victim prior to the EMS increases with declining distance. However, even with distances between 400 and 500 m some MRs reached the scene before the EMS (Fig. 4). Judged on our findings we believe that the proportion of MRs per square km^2 in an urban area found in this study may serve as a rough estimation for the number needed for further surveys.

The numbers of MRs voluntarily participating without any compensation and facing potentially unpleasant situations reflects the average citizen's strong commitment and willingness to help others in need.

4.3. Comparison of simulation and real life study and overall results

In the simulation study 72% of simulated OHCAs were reached first by an MR and the corresponding proportion in the real life environment was 45% amongst all cases and 56% amongst true OHCAs. The results are expected since the simulation study was carried out during controlled and ideal circumstances. Pre-testing revealed difficulties in measuring the time intervals of dispatched MRs to real life suspected OHCAs. To avoid inaccuracy of reported time intervals the outcome variable yes or no regarding the arrival of the MRs before the EMS was chosen. To not be able to show the amount of time gained with the use of the MPS is, however, one of the major drawbacks of the study. Also, the study was not designed to measure survival or CPR outcome. Nonetheless, our results indicate that MPS technology can be used to recruit lay responders to OHCAs and to increase the proportion of OHCA victims receiving bystander CPR.

4.4. Implications in the context of public access defibrillation (PAD) and bystander CPR

The EMS dispatching of lay responders with MPS may offer future possibilities. A database containing the geographical location of AEDs can be integrated within the MPS. Lay responders can then be directly dispatched to suspected OHCAs to perform CPR while other nearby lay responders are directed to deploy the closest AED. The overall effect of such a system has an even greater potentiality compared to the system used in this study but on the other hand potential time gains could easily be lost when some of the dispatched MRs have to run for the closest AED before trying to reach the place of the suspected arrest. Although some evident difficulties exist, we believe that the method might be used to activate AED-carrying MRs such as security guards, hotel personnel and taxi drivers to nearby OHCAs. Further, AEDs can be placed in moving objects and not necessarily be distributed to high incidence sites to be used.[8] One of the disadvantages with PAD programs is that they rely on "on site" activation in to be successful.[9] If an OHCA is taking place across the street the AED will probably not be deployed.[10]

5. Limitations

(1) MRs response times in the real life study, resuscitation outcome, proportion of bystander CPR performed by others then MRs or survival was not measured in this pilot-phase of the project.
(2) EMS and mobile phone dispatched responders were alerted to suspected OHCAs and not only to true cardiac arrests.
(3) Due to legislation or different mobile network infrastructure, the system used in our survey may not be applicable in other countries.
(4) Baseline EMS service was set as a reference although a dual dispatch system including police and fire department has been used in Stockholm during the last three years. The MRs were not compared to other first responders.

6. Conclusions

Mobile positioning systems can, in an urban setting, be used to identify and recruit nearby CPR-trained citizens to suspected OHCA for bystander CPR prior to ambulance arrival. Further studies are needed to evaluate potential effects on clinical outcome.

Conflict of interest

Tomas Stark has contributed as author to this article with technical design an input regarding the "Mobile Lifesaver Service". Tomas Stark is employed by LEKAB Communication Systems AB and is also a stockholder in the LEKAB Group. Besides, others did not declare any conflicts of interest.

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III

SURVIVAL AFTER PUBLIC ACCESS DEFIBRILLATION IN STOCKHOLM, SWEDEN.

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ABSTRACT

Background

In Stockholm County, a first responder system has been implemented in parallel with a Public Access Defibrillation (PAD) program. Additionally, the number of "wild" public Automated External Defibrillators (AEDs) has increased. The aim of this retrospective study was to evaluate the impact on survival from different defibrillation strategies in out-of-hospital cardiac arrests (OHCA)s available for PAD. The aim was also to compare a structured PAD-program (with focus on education, logistics and information) with defibrillation by on-site "wild" AEDs.

Methods

All OHCAs in Stockholm County 2006-2012 were eligible for the study. Witnessed arrests outside home of cardiac origin and with ventricular fibrillation (VF) or ventricular tachycardia (VT) were considered subjects for PAD. The sites within the structured PAD program increased from 60 to 135 during the study period. The "wild" AEDs outside the PAD program increased from 178 in 2006 to 5016 in 2012. 47 fire and 104 police units were available for dispatch as first responders.

Results

Of 6532 EMS treated OHCAs, 7 % (n=474) were defined as subjects for PAD. Of these, 69 % (n=326) were defibrillated by the emergency medical system (EMS), 11% (n=53) by first responders and 16% (n=74) by public AEDs. Survival to 1-month was 31% (n= 101) in cases defibrillated by the EMS, 42 % (n=22) in cases defibrillated by first responders and 71 % (n=51) in cases defibrillated by public AEDs. The AEDs within the structured PAD program were used in 28 % (21/74) of the public AED cases.

Conclusion

In OHCAs subjects for PAD, public AEDs use increased as the numbers of public AEDs increased. PAD significantly contributes to survival in terms of lives saved with survival rates as high as 71%. A structured AED program is more effective then "wild" AED dissemination in regards to AED usage ratio.

INTRODUCTION

The majority of patients suffering out-of-hospital cardiac arrest (OHCA) can initially be treated with defibrillation[1,2]. However, as minutes pass the initial and treatable rhythm of ventricular fibrillation (VF) or ventricular tachycardia (VT) deteriorates into asystole, and survival becomes dismal[3]. Low survival rates, in average 5-10%, are thus mainly caused by long time intervals from arrest to defibrillation[4,5]. To shorten response time,[6] first responder systems with dual dispatch of fire/police services in response to OHCAs have been implemented[7].

Dissemination of lay operated automated external defibrillators (AEDs) in public places, a concept known Public Access Defibrillation (PAD), is another strategy to deliver lifesaving shocks to OHCAs victims within the first few minutes[8]. During the last decade the spread of public AEDs throughout the world is striking. Only in Japan, the number of AEDs increased from just below 10 000 to just over 80 000 in 3 years (2007-2009)[9]. However, unsuccessful placement, negative perceptions and lack of awareness among the public leaves most AED unused[10]. Dissemination of AEDs throughout society may happen in two different conceptual ways, either as “wild AEDs”[11] or as a part of a structured programme with a trained response and a strategic selection of sites[12]. Little is known about the effect on survival from these two different approaches.

In 2001, 1-month survival following OHCA in Stockholm, Sweden was only 2.5 %[13]. To increase survival the Saving Lives in the Stockholm Area (SALSA)-project was launched. The main aim of the SALSA-project was to decrease time intervals in OHCA by dual dispatch of fire fighters in parallel with standard emergency medical services (EMS) and the preliminary results have been described elsewhere[14]. An additional aim was to evaluate the outcome of a structured PAD program within the Stockholm County were significant resources were spent on education, logistics and information at the participating sites.

The aim of the current study was to evaluate the impact on survival in patients available for PAD from three different defibrillation strategies; (a) PAD with AEDs on-site, (b) defibrillation by first responders and (c) defibrillation by the EMS. A second aim was to compare defibrillation within a structured on-site AED program (with focus on education, logistics and information) to defibrillation by on-site “wild” AEDs.

METHODS

Study design, patients

The study was an open retrospective observational study and included all patients suffering OHCA within the Stockholm County and in whom resuscitation was attempted by the EMS. The study period was 1st of January 2006 to 31st of December 2012. The local ethical board in Stockholm approved the study.

Study area, EMS-system and dispatch of first responders

The Stockholm County covers 6519 sq km and holds mostly rural areas except the most central parts of Stockholm and suburbs. At the end of the study period the county population was 2 054 343[15]. The average incidence of OHCA during the study period was 46/100 000/year. The national emergency number is dialed in case of a medical emergency and there is one single EMS dispatch centre receiving all calls within the county. Ambulances are dispatched in a two-tier system and all ambulances are equipped with AEDs. An ambulance carrying a nurse trained in anesthesiology and in advanced life support is always dispatched to suspected OHCAs. There are 58 ambulances available for dispatch at day (7 am to 9 pm) and 38 at night and the number did not change during the study period. From the year of 2006 all 47 fire stations in the county of Stockholm were participating in the SALSA project. In case of a suspected OHCA, AED equipped fire-vehicles were dispatched to suspected cardiac arrests in parallel with ambulance (EMS). In addition, an increasing numbers of police vehicles were also available for dispatched to suspected OHCAs. The number of police vehicles available for dual dispatch increased from 35 in the beginning of 2006 to reach a number of 104 in 2012.

The SALSA-PAD program

The Saving Lives in the Stockholm Area (SALSA)-project was launched in early 2005 and consisted of two entities: (a) introduction of dual dispatch of fire fighters and police in parallel with standard EMS and (b) a structured PAD-program.

The PAD-program within the SALSA-project started in 2005 with a pre-start run in period of 1 year. In 2005, 30 sites were approached with an offer to participate in the PAD program. Property owners, site managers and security companies of traditionally high incidence sites[16], such as big shopping malls, transportation hubs, and airports were targeted. If the site purchased the AED(s), the SALSA PAD-program committed to give free instructional training in standard basic life support (BLS) and AED use. The goal was that each site would be self-supporting in subsequent staff training of BLS and AED use. A formal agreement was signed on behalf of the SALSA PAD-program and the participating site. The SALSA PAD- program pledged to support each site and to plan and optimize the local response to suspected OHCA. This included: training of staff, alarm plans, awareness campaigns, signs and official posters as well as AED placement. The site, on the other hand, signed upon to have their personnel trained in BLS and AED use with re-training once a year and to report usage to the project management in a structured manner. As the number of sites increased above 60 in 2006 no more active recruitment was made. Participant sites were from the year of 2006 only recruited as an initiative from the sites themselves and the number of sites increased yearly to reach 135 in 2012.

SALSA PAD-sites surveys and follow up

During the study period two surveys were made about the awareness and knowledge of the SALSA–PAD program at different participating sites. The surveys were made with the purpose of identifying barriers for AED use and to gain knowledge on how to optimize the informational aspects and implementation of the PAD-program. The first was made in 2009 with a follow up in 2010. The survey included questions to different categories of staff such as security personnel and clerks at major participating sites (airports and shopping malls). Staff members were randomly approached on site and a structured protocol was used including question such as if the person was trained in BLS and AED use, if they were aware of the PAD program if they had got information on how to act in case of an OHCA or if the new were the AED was placed in if they would be willing to use it. Based on the result of the survey informational actions were taken. This included activities with public shows of CPR and AED use and informational campaigns targeting both staff and the public.

"Wild" AEDs outside the SALSA PAD-program
During the last decade a rapidly increasing number of AED have been purchased "over the counter" by local initiatives outside the traditional health care system in the Stockholm county. The number of AEDs in Stockholm outside the SALSA PAD-program was based on information received from all 12 major AED wholesalers in Stockholm. The number of yearly sold AEDs was anonymously obtained. These AED were not supervised in any structured manner in contrast to those within the SALSA PAD programme.

Data collection and definitions

Swedish Cardiac Arrest Registry (SCAR)
Data was collected from the Swedish Cardiac Arrest Registry (SCAR), ambulance records, the EMS data systems and incident driven report forms from SALSA PAD-sites. The SCAR is a quality register supported by the Swedish National Board of Health and Welfare. The registry covers all ambulance organizations in Sweden. All cases of EMS treated OHCAs is reported to the SCAR. Data is reported by the EMS crew as a web formula according the Utstein template[17] with a detail description of time intervals, etiology, primary rhythm, witness status, drug administration and patient outcome. The formula is then reviewed and completed by the head physician of the ambulance organization. The SCAR has thoroughly been described elsewhere[18].

From the year of 2010 it is possible for the EMS crew to state if a bystander uses a public AED. Additionally, data reported to the SCAR, ambulance records and event driven report forms from the sites participating in the SALSA PAD-program and from fire and police units responding to OHCAs were individually reviewed for every OHCA in the present study.

Definitions
All witnessed OHCAs that occurred outside home with presumed cardiac etiology and VF/VT at first rhythm analysis was regarded as subjects for PAD. If defibrillation was advised by the AED when applied, the primary rhythm was accounted for as VF or VT. Crew witnessed cases were cases of OHCA witnessed by the EMS crew. Non-EMS treated cases were cases were the EMS crew not started or immediately ceased treatment upon arrival due to ethical reasons or obvious signs of death.

All AEDs reported by wholesalers and AED within the SALSA-PAD program were assumed to be active and accessible during the entire study period. 1 AED-year was defined as 1 one year of AED activity. The number of cumulative active AED-years during the study period and the ratio of AED usage in relation to active AED-years were calculated.

Patient outcome

Patient outcome of survival to one month was collected from the Swedish National Death Registry.

Results

All OHCA patients, patient flow chart

As seen in Figure 1, there were 6532 OHCA cases in where resuscitation was attempted by the EMS during the study period. 71 % (n=4607) were due to cardiac origin and out of these 54 % (n=2504) were witnessed. In 931 (37%) cases the OHCA occurred outside home and in 51 % (n=474) of these, VF or VT was the first recorded rhythm.

In 474 (7%) out of 6532 OHCA cases defibrillation was carried out in public. These cases were thus considered as potential subjects for PAD in accordance with above stated definition and included in the final analysis (Figure 1).

Characteristics, location and outcome of patients defibrillated at public locations

As seen in Table 1, the response time for the EMS were 2 minutes shorter in OHCAs defibrillated by the EMS as compared with first responders or Public AEDs (6,1 vs. 8 vs. 8,7 min). The majority of all patients were men (88%). Mean age was 66 years. Bystander CPR rates were 88 % for all patients and 83 % for EMS treated cases.

Outcome data are presented in Figure 1 and Table 1. Among cases defibrillated at public locations, 69 % (n=326) were defibrillated by the EMS, 11 % (n=53) by a first responder and in 16% (n= 74) the first shock was delivered by a Public AED.

When a public AED was used, 1-month survival was 71% (51/72) ($p<0.001$). If the first shock was delivered by the EMS, 1-month survival was 31 % (101/326) and if the shock was delivered by first responders 42 % (22/53) survived to 1-month. Return of spontaneous circulation (ROSC) before ambulance arrival was 54 % (n=40) if a Public AED was used compared to 15 % (n=7) for the first responder group (Table 1). Among non-shockable rhythms, overall 1-month survival was 5 %, (n=21).

Proportion of defibrillated patients with public AEDs versus dispatched units (EMS/First responders)

As seen in Figure 2, the proportion of patients defibrillated by public AEDs steadily increased during the study period from 5 % in 2006 to 23 % in 2012. Concurrently, the proportion of patients susceptible for PAD and defibrillated by the EMS decreased during the same period from 78 % to 64 %. The proportion of patients defibrillated by first responders remained relatively unchanged.

Number of AEDs sold outside the health care system in the Stockholm County
Based on wholesale number reported by main suppliers in Sweden there were an increase in the numbers of AEDs sold per year from 178 in 2006 to 1284 in 2012. As seen in Figure 3, the cumulative numbers of AEDs sold outside the health care system in the Stockholm County increased to reach 5016 in the end of 2012. There was a correlation between the cumulative numbers of AEDs and the annual number of a patients defibrillated with a public AED.

The SALSA PAD-program versus "wild" AEDs, efficacy and impact on survival
Out of 74 cases defibrillated with a public AED, 40 % (n=21) was defibrillated with a Public AED from the SALSA PAD-program (Table 3). There were no significant differences in survival between groups dependent on if defibrillation was made with a Public AED as part of the SALSA PAD-program (75%, 15/20) or by a "wild" AED (69%, 36/52).

In Table 3, the cumulative active AEDs-years (i.e exposure) in relation to the cumulative number of defibrillated OHCAs were calculated. The "wild" AEDs were active for 14758 cumulative AED-years vs. 684 cumulative active AED-years for the AEDs within the SALSA PAD-programme. The exposure/usage ratio was calculated for each group. The usage/exposure was about 9 times higher for AEDs within the SALSA PAD program (33 AED-years per defibrillated OHCA) compared with "wild AEDs" (279 AED-years per defibrillated OHCA).

The locations of all OHCA that were defibrillated with a public AEDs are shown in Table 2. Airports, care facilities, and sport facilities were sites with a high incidence of Public AED usage.

Discussion

In this paper we report the impact on survival from different defibrillation strategies in OHCAs suitable for PAD. To our knowledge, this is the first paper that in depth describes the effects of two conceptually different strategies for on-site PAD: "over the counter and wild" AEDs in comparison with a monitored and audited PAD program with trained response. Our main finding is that defibrillation by public AEDs significantly contributes to survival in terms of lives saved with a survival rate of 71 %. In the present study, more then twice as many patients were saved as an effect of PAD in comparison with the number of lives saved by first responders. A second major finding is that a structured AED program with focus on education, logistics and information seems to be more efficient than the spread of "wild" AEDs in regards to number of OHCAs defibrillated per AED.

Outcome of different defibrillation strategies
In this paper we report a very high survival rate of 71 % after usage of public AEDs. This

is in line with data reported from previous PAD landmark studies carried out in limited settings such as casinos and at airports[19,20]. We conclude that if an AED is applied within the first minutes more than two thirds of these patients can be saved. A recent nationwide study from Denmark also reports similar survival rates (around 70%) if a public AED were used[21]. In combination with an increased usage of PAD over time, this is hopeful in regard to the fact that recent studies have pointed at a decreasing incidence of VF during the last decade, making even fewer patients available for PAD[22].

Our data demonstrate that, among patients defined as subjects for PAD and defibrillated by EMS or first responders, survival was 31 % and 42 % respectively. The total number of survivors defibrillated with a public AED was more than twice as many survivors defibrillated by first responders (51 vs. 22). This study thus demonstrates that, in patients defined as subjects for PAD, defibrillation with public AEDs contributes to a significant proportion of survivors. The proportion of survivors defibrillated by a public AED is about the half of all survivors defibrillated by the EMS but clearly outnumbers the survivors defibrillated by first responders in this population of patients. In this patient population PAD therefore plays an important role.

All OHCA patients and patients defined as subjects for PAD.
In this study, only 7 % of all EMS treated OHCAs were defined as subject for PAD and defibrillated in public. The rationale behind this definition is that in order to be accessible for PAD several conditions should be fulfilled. First, the arrest should be of cardiac origin since the majority of non-cardiac arrests presents with non-shock able rhythms[23]. Second, the arrest has to be witnessed in order to bring the AED to the patient's side in reasonable time. Third, the arrest should take place outside home since several studies have not shown any benefit of PAD programs in residential areas or at home, even in patients increased risk for OHCA[24]. Finally, the patient must have a primary rhythm of VT or VF for defibrillation to be possible. However, this distinction disqualifies the majority of all OHCAs that take place at home, are un-witnessed or in locations not suitable for PAD. Taking all OHCA into account the impact of on-site PAD on overall survival will be minor. Therefore, new strategies that could increase help from "on-site" citizens (such as mobile phone dispatching of lay responders, AED maps available in dispatch centres and for lay responder[25]) are needed. Furthermore, some of these promising strategies might also have the benefit and possibility to also reach those OHCA at home, currently not benefiting from PAD.

It should also be recognised that first responders are normally dispatched to all OHCA, thus also to residential OHCAs. Therefore, the comparison of defibrillation strategies (between EMS, first responders and public AEDs) may be unjust in regard to the total number of OHCAs. The contribution on overall survival by the first responder program in SALSA is beyond the scope of this article.
Increased proportion of defibrillated patients with public AEDs
During the last decade the numbers of public AEDs have increased beyond expectations in the western world and an AED is now virtually within reach in every airports and public

transportation hub and this is true also in Stockholm County. Based on wholesale numbers from all major retailers of AEDs in the Stockholm County the number of AEDs outside the healthcare system increased massively (Figure 3). As a plausible consequence, the proportion of patients defibrillated by public AEDs increased over time with a concurrent decrease in patients defibrillated by the EMS and first responders. This effect may also (besides an increasing number of public AEDs) be second to other explanations such as increased awareness, shift of values and public information.

The SALSA PAD-program versus "wild" AEDs and impact on survival
The number of "wild" AEDs outside the SALSA PAD-program was superior to the number of PAD sites within the program (5016 vs. 135 in 2012) as demonstrated in Table 3. However, out of all cases defibrillated by a public AED, the proportion of patients defibrillated by an AED within the SALSA-PAD-program was 28 % (n=21). The number of AEDs and the time for how long each AED were accessible can be seen as the total time of AED-exposure for the population of OHCAs available for PAD and is expressed as AED-years. Therefore the total cumulative number of AED-years (i.e exposure) was calculated. The "efficacy ratio" of AEDs usage in relation to active AED-years was found to be about 9 times higher within the SALSA PAD program compared to that of "wild" AEDs. The lowest ratio was 279 AED-years per defibrillated OHCA for the "wild" AEDs compared to 33 AED-years per defibrillated OHCA for the AEDs in the SALSA PAD programme. This translates to about 1 defibrillated OHCA for every 33d AED annually in the SALSA PAD-programme.

In a study from Copenhagen with a similar setting, 100 AEDs were placed around the centre of Copenhagen but none were used in during one year[26]. In the SALSA PAD program the sites were strategically selected and to a large extent high incidence sites such as airports, ferry terminals, shopping malls, and transportations hubs. No stringent inclusion criteria were used; however, all venues had to fulfil the condition of having a large number of persons present during opening hours.

Although the "wild" AEDs being less efficient in regard to usage ratio, it is recognized that the majority of patients were defibrillated with an AED outside the structured PAD program. We therefore conclude that a strategic and structured approach is superior in efficacy but wide dissemination that relies on private initiatives is also important and should be encouraged

During the study period, survey investigations were annually carried out in 2009-2011 with the purpose to identify barriers for AED use. The survey and information activities were then followed up with information campaigns and different site-specific measures in order to optimize local response. We believe this to be a key factor in the successful implementation of the SALSA PAD-program. Although there was nearly 50 times more AEDs outside the SALSA PAD-program the efficacy of the AEDs within the program were high, and nearly one third of all OHCAs that were defibrillated with a public AED was defibrillated by an AED within the SALSA PAD program.

Limitations

1. The exact number of AEDs outside the SALSA PAD project was not known but based on wholesale numbers.
2. The number of applied AEDs was not known, only the number of AED that was used to deliver shocks.
3. Time from arrest to defibrillation by public AEDs or for AEDs used by the first responders could not be obtained.
4. AEDs were not analysed in order to gain more objective information about CPR, time to defibrillation or first rhythm.

Conclusions

Among OHCAs that are subjects for PAD, defibrillation by public AEDs significantly contributes to survival in terms of lives saved with a high survival rate of 71%. Both a structured AED program as well as spread of "wild" AEDs demonstrates very high survival rates, but a structured AEDs program is more efficient in regard to AED usage ratio.

Figure 1. OHCA in stockholm County 2006-2012

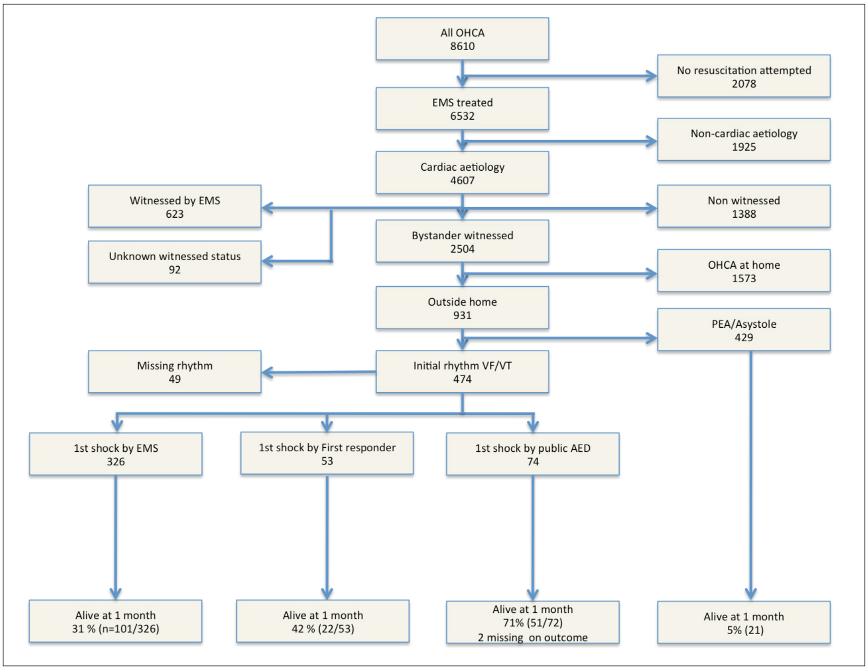

Figure 2. Proportion (%) of patients available for PAD defibrillated by; EMS; First responders and public AEDs

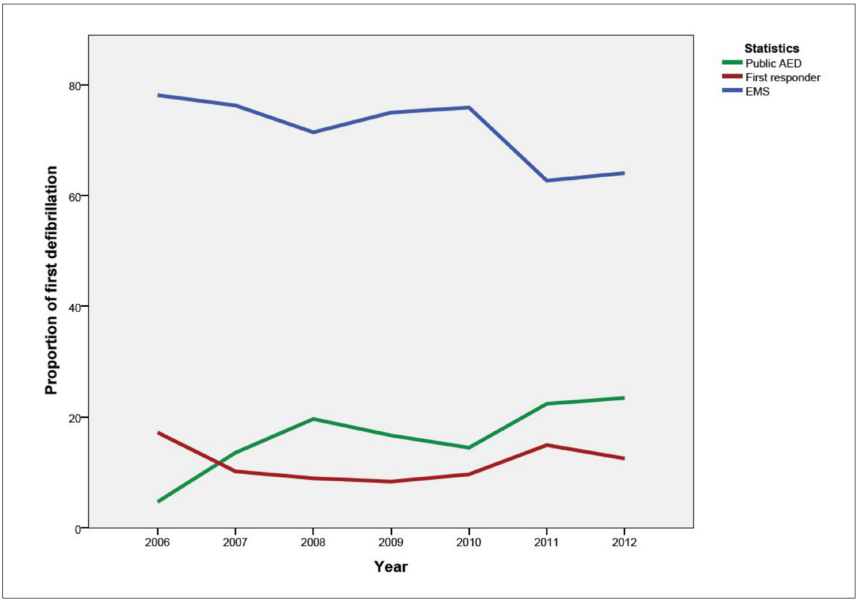

Figure 3. Defibrillation by public AEDs (n) in relation to the cumulative number of Public AEDs sold in Stockholm County 2006-2012

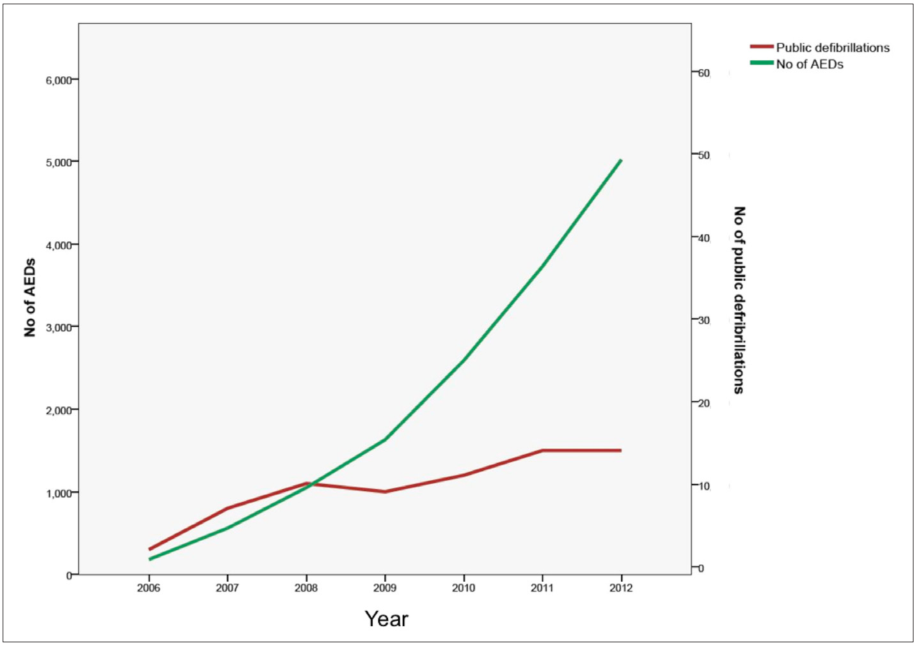

Table 1. Characteristics and outcome of defibrillated patients defined as subjects for PAD

Defibrillation by:	Public AED (n=74)	First responder n=53	EMS n=326	All n=474
Age median (q1-q3)	67 (60-75)	62 (57-73)	66 (57-76)	66 (57-75)
Men	85 % (n=63)	92 % (n=49)	88 % (n=287)	88 % (n=417)
EMS response time, minutes, median (q1-q3)	8 (6-12)	8,7 (7-13)	6,1 (4-10)	7 (4,4-10,2)
Bystander CPR before arrival EMS	100 %	100 %	83 % (n= 271)	88 % (417)
CPR by:				
-Bystander	62 % (n=46)	34 % (n=18)	80 % (n=261)	69 % (n=327)
-First responder	0 %	66 % (n=33)	14 % (n=46)	12 % (n=57)
-Medically trained	38 % (n=38)	0 %	5,8% (n=19)	19 % (n=90)
Outcome				
-ROSC prior to ambulance	54 % (n=40)	15 % (n=7)	0 %	11% (n=5)
-Admitted alive	81 % (n=60)	62% (n=32)	51% (n=166)	57% (n=270)
-ROSC	84% (n=62)	66% (n=33)	55% (n=179)	67% (n=318)
1-month survival Missing P-value (survival 1 month)	71 % (51/72) 1 <0.001	42 % (22/53) 1	31 % (101/326) 0	39 % (174/453) 0

Table 2. Location of defibrillated OHCAs by public AED

Location	N	%
Office	6	8
Airport	7	10
Golf course	2	3
Gym	2	3
Sports facility	12	15
Mall	6	8
Station/Terminal	3	4
Outside (street, park)	8	11
Care facility (dentist, primary care)	21	28
Others	7	10
Total	74	100

Table 3. Patients defibrillated on-site: "Wild" AEDs vs. SALSA PAD-Program

Year	2006	2007	2008	2009	2010	2011	2012	Total	Survival
"Wild" AEDs									
1. No of OHCA	3	5	6	5	9	12	13	53	69% 36/52(1 missing)
2. No of available AEDs	178	556	1051	1631	2594	3732	5016	5016	
3. Cumulative nr of AED-years*	1246	3514	5989	8309	11198	13474	14758	14758	
4. AED-years per OHCA**								279	
SALSA AEDs									
1. No of OHCA	0	3	5	5	3	3	2	21	75% 15/20 (1missing)
2. No of available AEDs	63	68	87	98	112	121	135	135	
3. Cumulative nr of AED-years*	441	471	566	610	652	670	684	684	
4. AED-years per OHCA**								33	

*****_AED-year=1 AED active for 1 year. The assumption was made that all AEDs reported by wholesalers and within the SALSA-PAD program were active and accessible for PAD._

******_Number of AED-years (i.e exposure) per defibrillated OHCA._

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IV

IMPACT ON BYSTANDER CARDIOPULMONARY RESUSCITATION OF A MOBILE PHONE POSITIONING SYSTEM AND DISPATCH OF LAY VOLUNTEERS TO OUT OF HOSPITAL CARDIAC ARRESTS. A RANDOMIZED CONTROLLED TRIAL.

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ABSTRACT

Background

Bystander cardiopulmonary resuscitation (CPR) increases survival in out-of-hospital cardiac arrest (OHCA). A mobile phone positioning system (MPS) can locate mobile phone users geographically. The aim of this blinded randomized controlled trial was to investigate if bystander CPR rates could be increased when a MPS was used for dispatch of CPR-trained lay volunteers to nearby OHCAs.

Methods

In Stockholm, Sweden (April 2012 to December 2013) a MPS was used to locate and dispatch CPR-trained lay volunteers to nearby (within 500 m) OHCAs. In addition to dispatch of ambulance, fire and police services the MPS was triggered by the dispatcher in case of suspected OHCAs. Allocation to dispatch (intervention) or not dispatch (control) of CPR-trained lay responders was automated and blinded. Primary outcome was bystander CPR before arrival of ambulance, fire and police services.

Results

At study start 5989 CPR-trained volunteers had been recruited and the number increased to 9828 during the study. The MPS was triggered in 1813 suspected OHCA. 52% (n=949) were allocated to intervention and 48% (n=864) to control. Non-OHCA cases and ambulance crew witnessed cases were excluded (n=1146). In the final analysis of 667 OHCAs, 46% (n=306) were allocated to intervention and 54% (n=361 to control. The proportion of bystander CPR was higher in the intervention group 62% (n=188) compared with the control group 48% (n=172) (absolute difference 13.9 percentage points; 95% CI 6.2 to 21.2, p <0.001).

Conclusion

A mobile phone positioning system for dispatch of CPR-trained lay volunteers to out-of hospital cardiac arrests can significantly increase bystander CPR rates.

INTRODUCTION

Bystander cardiopulmonary resuscitation (CPR) before arrival of the emergency medical system (EMS) or first responders (fire and police services) is associated with an up to three-fold increase of survival in Out of Hospital Cardiac Arrest (OHCA)[1,2]. Still, low bystander CPR rates are a major obstacle for improved survival rates[3]. Traditionally, a mass educational approach has been the general way to improve bystander CPR rates[4]. However, this method is associated with significant costs and the casual effect from these programmes on bystander CPR rates is uncertain[5]. The vast majority of those trained will never have the chance to use their CPR-skills in real-life situation and therefore, alternative approaches are needed.

A mobile phone positioning system (MPS) gives the opportunity to instantly locate single mobile phone users geographically [6]. We hypothesized that the use of mobile technology in the context of OHCA could increase bystander CPR rates. With the use of a MPS, CPR-trained lay volunteers can be located and dispatched to nearby OHCAs by text messages and voice calls. This has been tried in a prior pilot[7] study but never in a randomized controlled trial. The aim of this blinded randomized controlled trial was to evaluate the impact on bystander CPR rates after implementing a MPS service for dispatching of CPR-trained lay responders to OHCA.

Methods

Study setting, Emergency Medical System and First responders

The study was designed as a community based blinded randomized controlled trial and was carried out in the County of Stockholm between 1st of April 2012 to 1st of December 2013 (ClinicalTrials.gov number, NCT01789554). The Stockholm County covers 6519 sq. km and has population of 2 091 473[8]. The incidence of EMS treated OHCA was 46/100000 in 2011. There is one EMS dispatch centre receiving all emergency calls and there are 58 ambulances available for dispatch during the day (7 am to 9 pm) and 38 at night. In suspected OHCAs, a two-tiered system is launched with one first responding ambulance and one additional unit carrying a nurse or doctor trained in anaesthesiology and advanced life support. Additionally, police and fire services (first responders) are simultaneously dispatched to all suspected non-traumatic OHCAs over eight years of age. There were 47 fire and 10 police units available for dual dispatch at night and daytime.

Mobile positioning system

A MPS can geographically locate single mobile phones. To locate mobile phones the MPS uses the known geographical location of communicating antennas and base stations. The angle of the communicating signal and the time it takes for the signal to travel back and forth can be used to increase accuracy, which in urban areas are approximately 0m to 75 m.[9]. For the purpose of this study, a tailored MPS-service was developed by LEKAB Communication Systems.

Recruitment of CPR-trained lay volunteers

CPR-trained lay volunteers were recruited to sign up for the MPS-service through advertising campaigns in different media and at CPR training courses. These volunteers were referred to as "SMS-lifesavers" (SMS i.e. short message system). The registration for the MPS-service was web based[10] and the volunteers entered the following data: age, sex, level of CPR-training, date of last CPR-training, e-mail, and phone number. An informed consent click box stating that the volunteers was over 18 years of age had former CPR training, agreed upon being positioned and dispatched to suspected OHCAs was mandatory for registration and activation of the service. No financial or other compensation was offered.

Dispatch of SMS-lifesavers.

All incoming emergency calls to the dispatch centre in Stockholm are always automatically geographically located. The dispatchers handle emergency calls according to a structured medical index. If an OHCA is suspected (i.e. unconscious not breathing normally) several actions are taken simultaneously according to a pre specified action plan. First, ambulance services are dispatched in parallel with first responders. Second, telephone CPR is offered if the witness has no prior training in CPR. Third, the dispatcher launches the MPS-service.

When the MPS is launched, data about the type of emergency, location, address, geographical coordinates and other information is exported from the dispatch centre computer system to the MPS-service. The MPS-service then compares the geographical location of the suspected OHCA to the current location of all SMS-lifesavers. The SMS-lifesavers located within a radius of 500 meters from the suspected OHCA receives a computer generated voice call and a SMS (short message system)/text message with information of the location of the arrest (figure 1). The SMS- lifesavers also receives a web link to a map showing the location of the suspected OHCA.

Randomization procedure

After launching of the MPS-service by dispatchers, computerized randomization was performed in a 1:1 ratio to either intervention or control. The randomisation was automatically performed within the SMS-lifesaver computer system by a modified standard function in Microsoft ™.NET 4.0[11]. In cases allocated to intervention, SMS-lifesavers were located with the use of the MPS service and dispatched by SMS/text messages and voice calls if they were present within 500 meters from the suspected OHCA. In cases allocated to control, SMS-lifesavers were located with the use of the MPS but no final dispatch was made with SMS/text messages or voice calls. Dispatcher was blinded for allocation and all investigators were blinded to allocation and outcome until final analysis was completed and randomization code was broken.

Patients

Inclusion criteria for *randomization* were all suspected OHCAs. Exclusion criteria for randomization were suspected OHCAs below 8 years of age and OHCAs due to drowning, trauma or suicide.

Inclusion criteria for *data analysis* were all EMS treated OHCAs in where the MPS-service was launched. Exclusion criteria for data analysis were all non-EMS treated OHCAs (due to ethical reasons, obvious signs of death or do-not resuscitate orders) and crew witnessed cases in where the MPS- service was launched.

Primary and secondary outcome.

Primary outcome was bystander CPR performed before arrival of EMS or first responders. Secondary outcomes were ventricular fibrillation (VF) or ventricular tachycardia (VT) at first ECG, return of spontaneous circulation (ROSC) and 30-day survival.

Definitions

Bystander CPR:	any form of (single or multiple) rescue breaths or chest compressions prior to arrival of ambulance, fire or police services. Telephone assisted CPR was not accounted for as bystander CPR.
EMS treated OHCA:	treatment of the patient by EMS crew with any form of cardiopulmonary resuscitation measures, including: basic life support, intravenous needle and administration of drugs, bag-mask breathing, intubation, laryngeal mask placement, or defibrillation.
Crew witnessed OHCA:	Cases of OHCAs where the arrest was witnessed by the EMS crew.
VF/VT	In cases where first responders arrived prior to ambulance, the initial rhythm was defined as VF) or VT if the automated external defibrillator advised shock at first analysis.

Data collection

Primary and secondary outcome data was obtained in the following order: (1) Ambulance records, (2) The Swedish Cardiac Arrest Registry (SCAR) which included 30-day survival data, (3) Survey data from SMS-lifesavers responding to suspected OHCAs alarms, (4) OHCA records from first responders. All ambulance organisations report resuscitation data to the SCAR[12] according to the Utstein guidelines[13]. First responders report data from resuscitation attempts according to the Utstein guidelines to the SAving More Life in Sweden (SAMS) database. A web survey was sent out to all SMS-lifesavers located within 500 m of suspected OHCAs for collecting data about resuscitation efforts by SMS-lifesavers and performance of the MPS-service.

Ethics

The study was approved by the local ethics board in Stockholm (2009/349-31, 2009/1798-3). For obvious reasons informed consent could not be collected at inclusion and this was accepted by the ethics board. All SMS-lifesavers agreed upon registration that their mobile phones could be positioned and that information received about suspected OHCA was not for spread to third parties. Data about positioning was kept for study use only. SMS-lifesavers could at any time werase all data and leave the project. SMS-lifesavers were also available to and get in contact with the project management in case of traumatic experiences. Debriefing was provided when requested by the Stockholm county fire department. The project management continuously reviewed potential adverse events (harm or risk for harm to patients or lay volunteers).

Statistics

Based on a pilot study and previously reported CPR rates from the County of Stockholm we hypothesized an increase in bystander CPR rates with 12,5 percentage points (50% to 62,5%) in OHCAs allocated to intervention. With a statistical power of 80 % and a two-sided significance of 5%, the sample size was calculated to a total number of 492 patients. A pre specified interim analysis was performed after 200 included patients for confirming inclusion rate and safety analysis. Power calculation was done in Sample Power 2.0.

The chi-square test was used to compare the proportion of bystander CPR (i.e. the primary end point) and the secondary endpoints between the intervention and the control group. We present the estimated difference in proportions between the control and intervention group and 95% confidence interval (CI) based on the asymptotic method with no continuity correction[14] (Table 2 and 3). To study if the proportion of bystander CPR differed between the intervention and the control group in different subgroups we used logistic regression. The interaction between the intervention and each of the baseline factors, one at a time, was tested with Wald test and we report the P-values.

Logistic regression was also used to study the associations between bystander CPR and the intervention and each of the other eight possible confounder factors (VF/VT, cardiac etiology, witnessed, location, gender, response time, age: categorized according to table 4, and the corresponding results after adjusting for these factors. The model strategy was as follows. First, we studied the associations between the bystander CPR and each of the factors one at a time. Second, we estimated an adjusted model with all the factors to study the effect of the interventions adjusted for possible confounders. Third, to study if the effect of the intervention differed between the intervention and the control group after adjusting for the possible confounders we tested possible two-way interactions between the intervention and each of the other factors. The results are presented as odds ratios and corresponding 95% confidence interval. Analysis was done in IBM SPSS version 22 and http://vassarstats.net/prop2_ind.htm. P-values were regarded significant below 0.05, two sided. Goodness of fit for the adjusted models was assessed with Hosmer and Lemeshow goodness of fit; P-values above 0.05 indicated an acceptable fit.

Results

SMS-lifesavers

During the pre study phase an increasing number of CPR-trained lay volunteers signed up for the MPS-service. At study start the number was 5989 and rose during the study to reach 9828 at the end of the study. Of 5989 SMS-lifesavers 48% (n=2898) were men. Mean age of SMS-lifesavers was 40 years.

Allocation of patients
As seen in figure 2, the MPS-service was triggered in 1808 cases of suspected OHCA and 52% (n=947) were allocated to control and 48% (n=861) to intervention. In suspected OHCAs allocated to *control*, 405 were non-OHCA cases, 12 cases were ambulance crew witnessed and 169 were true OHCA but not treated by the EMS due to obvious signs of death or ethical reasons. In suspected OHCAs cases allocated to *intervention*, 389 were non-OHCAs, 17 were crew witnessed and 149 cases were true OHCAs but not treated by the EMS due to obvious signs of death or ethical reasons. In the final analysis for outcome 667 EMS treated OHCAs were included, and 46% (n=306) were allocated to intervention and 54% (n= 361) to control.

Baseline characteristics of EMS treated OHCAs.
Table 1 shows baseline characteristics of all EMS treated OHCA included in the outcome analysis. There were no major differences in regard to baseline characteristics between the intervention and the control group.

Outcome
As shown in Table 2, there was a 13.9 percentage points (95% CI 6.2 to 21.2, p<0.001) difference in primary outcome with 61.6% (188/306) of patients receiving bystander CPR among OHCAs allocated to intervention compared to 47.8% (172/361) in cases allocated to control.

As seen in Table 2 there was a significant difference (9.5 percentage points difference, CI 2.0 to 16.9) between groups if telephone CPR was accounted for as bystander CPR with bystander CPR rates of 64.3% in the intervention group vs. 54.7% among controls. In other secondary outcomes: return of spontaneous circulation, initial rhythm or 30-day survival, no significant differences were seen.

Table 3 shows differences in bystander CPR between intervention and control according to subgroups. There were significant differences in bystander CPR between the different rhythms (p=0.034 for interaction) favouring intervention in the Asystole/PEA group compared with VF/VT. There were a significant difference in bystander CPR in favour for intervention within the following groups: cardiac aetiology, un-witnessed cases, location at home, male and female sex, age 60-79 years and response time < 6 minutes.

Table 4 displays the associations between bystander-CPR prior to the arrival of first responders and EMS. Factors that were independently associated with bystander CPR prior to arrival of first responders and EMS were activation of the MPS (i.e. intervention), response time < 6 minutes, age < 40, outside home and witnessed cases. After adjustment for other factors, the association between bystander CPR and the intervention remained (OR 1.7, 95% CI 1.2 to 2.5). In addition, the interaction between rhythm and intervention showed that the odds for bystander-CPR was higher (OR 2.1, 95% CI: 1.4 to 3.1) among OHCAs with Asystole/PEA allocated to intervention compared to those allocated to control.

SMS lifesaver data and survey data
As displayed in Table 5, there were no SMS-lifesavers located within 500 meters in 57 of all 306 cases (19%). In 199 (65%) cases there were one or more SMS-lifesaver (s) that stated that they tried to reach the scene of the OHCA and in 70 (23%) of all cases the SMS-lifesaver reached the OHCA before arrival of EMS and first responders. In 40 (13%) of the EMS-treated OHCAs, one or more SMS-lifesaver stated that they were first to start CPR.

Adverse events
There were no adverse events reported. However, there were one incidence were lay volunteers contacted the project management for the need of debriefing. There were no reported cases of thefts or other forms of misbehaviour among lay volunteers arriving at the scene of private homes.

Discussion

This is the first randomized controlled trial evaluating a full scale implementation of a mobile phone positioning system used for locating and recruiting lay responders to OHCAs for bystander CPR. In this trial, engaging more then ten thousand lay volunteers, our main finding is a highly significant increase in bystander CPR rates from 48% to 62% in cases were the SMS-lifesaver system for locating lay volunteers was triggered. The increase in bystander CPR was seen weather or not telephone CPR was accounted for as bystander CPR.

The logistic regression showed that bystander CPR prior to first responder/EMS arrival was independently associated with the activation of the SMS-lifesaver system. Other factors that usually are associated with bystander CPR were also confirmed in our study (location outside home, short response time, and witnessed arrest)[15]. In the subgroup analysis an increase in bystander CPR in cases allocated to intervention was seen in patients suffering their OHCA at home as well as among un-witnessed cases. This probably reflects the fact that in patients in this group, occasional bystanders do not start CPR in the same proportion as a witnessed arrest out in the street. This, we believe, strengthens the results of this intervention since patients in this category seldom receives bystander CPR[16].

Two-thirds of all cardiac arrest occur in people's homes[17], a fact that intensifies the need to find new strategies to reach these patients. The increasing spread of publicly accessible defibrillators in Public Access Defibrillation (PAD) - projects has usually only been focusing on cases occurring in public places. To our knowledge this is the first time the concept of using mobile phone positioning technology as a successful strategy for sending lay rescuers to treat all cardiac arrest, also those occurring in people's homes is used and evaluated in a randomized trial.

No significant differences between the intervention and comparison groups were found for the secondary outcomes of 30-day survival and of shockable rhythms. This study was not designed for detecting differences in survival or ROSC. It has, however, repeatedly been demonstrated that bystander CPR is associated with increased survival rates[18,19]. There are a few other sites where mobile phone technology and logistics also are used in a similar manner[20,21], but to our knowledge it has never been evaluated in a randomized trial. Furthermore, this study is the first to report a significant increase in bystander CPR, not subsequent to mass education and information campaigns among the public carried out over several years, instead novel technology is used. The logistics and approach differs between sites but the main idea is similar. In our system lay responders are geographically positioned and dispatched *only* if within 500 m from the suspected arrest and direct feedback from lay responders is received from a web survey. Positioning of lay volunteers and dispatch to *all* OHCA also at home may be problematic in other countries due to legislation besides that we believe these results to be valid and the logistics applicable to similar settings of urban areas like Stockholm.

In a recent publication from Denmark Wissenberg and colleagues report an increase in bystander CPR from 21% to 45% over a period of 9 years as a result of a massive national CPR promoting initiatives at several different levels in society[22]. Furthermore this was associated with a concurrent increase in survival over time. Increasing bystander CPR rates of this magnitude is usually the result of a demanding work were mass education of lay people and change of attitudes takes several years to accomplish and may takes large resources into account[23]. In this study a novel strategy was successfully used were designated and motivated lay volunteers voluntarily signed up to volunteer and use their skills. We believe that increasing CPR rates of this magnitude in a few years taking modest resources into account can have profound impact in how CPR training among the public is best targeted and used.

SMS-lifesavers

During the pilot study and the pre study phase lay volunteers were recruited through advertising in newspaper and other media. At first about 1200 lay volunteers registered. During the following years the number of lay volunteers increased forcefully without further recruitment measures to reach nearly 10 000. This reflects the massive commitment from lay people that are willing to help out in case of OHCAs occurring nearby. The lay volunteers were evenly distributed regarding to sex and most were middle aged. Also, impressively there were no major adverse events during the study period. No reports of misbehaviour, thefts or other problems were reported despite that the majority of cases occurred in people's homes.

Allocation of patients

The allocation sequence of patients was fully computerized and blinded for researchers and dispatchers. In case of suspected OHCA fulfilling criteria for eligibility dispatchers triggered the SMS-lifesaver service. Allocation was then made after the dispatcher triggered the SMS-lifesaver service. Independently of allocation to control or intervention the SMS-lifesaver service geographically located all lay responders. In case of allocation to control no final SMS and voice call was made to mobile phones located within 500 m. Allocation between groups were somewhat unevenly distributed in suspected OHCAs with 48% versus 52%. In the final analysis the majority of all suspected OHCA were excluded resulting in an increased skewness between group sizes with more patients allocated to control 46% versus 54%. The randomization sequence was validated, blinded and fully computerized and there was no indication that the mismatch between groups occurred in no other way then by chance.

Baseline characteristics

There was no significant difference in baseline characteristics between groups supporting that there were no selection bias at randomization. Response time of first arriving unit (first responder or EMS) was relatively short indicating that the MPS and dispatch of lay SMS-lifesavers is functional even if a response time is short. Also, the subgroup of patients with short EMS/first responder response times seemed to benefit the most. Moreover, a high proportion of baseline CPR rate of 48% was found in the control group. This means that our system of mobile phone dispatched lay volunteers was not only evaluated against standard EMS but also against dispatched first responders (fire department and police) and in a setting with relatively high baseline CPR rate. In the Stockholm County first responders are first to arrive at the scene of suspected OHCAs in about 40% of all cases[24]. Thus, our SMS-lifesaver system might have an even greater impact in our cities with "only" EMS-services and lower baseline bystander CPR- rates.

Future implications

There is an emerging field in OHCA science dedicated to strengthen the links in the chain of survival concept through use of new technology. Kovic and Lulic propose the use of an alternative "mobile phone in the chain of survival"[25]. The "in everyone's hand" smartphones can be used for CPR training, audio-visual feedback, location of automated external defibrillators and communication via multimedia with the dispatch centre. Still, there is little evidence of the impact of this technology in real life settings. Our study is the first randomized controlled trial to demonstrate evidence of the potential use of this novel technology in the context of OHCA. In the future lies the possibility to add automated external defibrillator registries for not only dispatch of lay responders for CPR but also to fetch the nearest AED. We are now planning a integration of the Swedish National AED registry[26] holding about 10 000 validated AEDs with the SMS-lifesaver service. This will give the possibility not only to dispatch SMS-lifesavers for CPR but also to fetch and recruit nearby public AEDs for instant usage. This novel approach probably has the potential to increase overall survival rates.

Conclusion

A mobile phone positioning system and dispatch of CPR-trained lay volunteers to nearby Out-of- Hospital Cardiac Arrests can safely be used to significant increase bystander CPR.

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Limitations

1. This study was not powered to study survival.
2. Time from cardiac arrest to arrival of SMS-lifesavers could not be objectively measured. Instead subjective reports from lay volunteers were used as reference.
3. The current study was a single centre study using only one dispatching centre. In addition due to legislation and difference in EMS systems the result may not be fully applicable to other contexts.
4. The MPS were not used in cases of trauma, drowning, and suicide and in OHCAs under the age of 8 years. Further the MPS was not used during nighttime. The results can therefore not be applied to OHCA occurring during these circumstances.
5. The quality of CPR by lay responders was not evaluated.

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Table 1. Baseline characteristic of 667 EMS treated OHCAs in final analysis

	INTERVENTION (dispatch of SMS-lifesavers)		CONTROL (no dispatch of SMS-lifesavers)	
	n	%, median (q1-q3)	n	%, median (q1-q3)
Age (years)		71.0 (62.5- 81.3)		73.5 (61.8 – 83.3)
Sex (male)	213	70,5	225	64,1
Location				
-Home	209	69,0	251	71,1
-Not at home	94	31,0	102	28,9
Aetiology				
-Cardiac	246	81,2	282	80,1
-Non-cardiac	57	18,8	70	19,9
Witness status				
-Witnessed	165	56,9	186	57,6
-Non-witnessed	125	43,1	137	42,4
Telephone assisted CPR	10	4,0	23	8,3
Call to EMS arrival,		8.3 (5.4 – 12.8)		8.2 (5.5-11.9)

Table 2. Comparison between intervention and control group for primary and secondary outcomes

	Intervention (dispatch of SMS lifesavers)	Control (no dispatch of SMS lifesavers)	Difference (95% CI) Percentage points	p value
Primary outcome				
Bystander CPR	61.6 % (188/305)	47.8 % (172/360)	13.9 (6.2 to 21.2)	<0.001
Secondary outcome				
30-day survival	11.2 % (32/286)	8.6 % (28/326)	2.6 (-2,1 to 7.8)	0,281
Return of spontaneous circulation	29.4 % (90/306)	29.1 % (105/361)	0,3 (-6,5 to 7,3)	0,927
Shockable rhythm (VF/VT)	19.3 % (58/301)	17.3 % (60/347)	2.0 (-4.0 to 8.0)	0,515
Bystander CPR (telephone CPR included)	64.3 % (196/305)	54.7 % (197/360)	9.5 (2.0 to 16.9)	0.013

Table 3. Comparison of bystander CPR (primary outcome) between the intervention and control group according to subgroups

	Sub-group	Intervention group Bystander-CPR (n/tot)	Intervention group Bystander-CPR (%)	Control group Bystander-CPR (n/tot)	Control group Bystander-CPR (%)	Difference (95% CI) Percentage points	P-value for interaction between treatment and each factor
All patients	-	188/306	61,4	172/361	48,0	13,9 (6,2 to 21,2)	
Rhythm	VF/VT	36/58	62,1	43/60	71,7	-9,6 (-25,8 to 7,3)	0,034
	Asytole/PEA	148/243	61,2	122/287	42,7	18,4 (10 to 26,5)	
Etiology	Cardiac	151/246	61,3	134/282	47,5	14,1 (5,6 to 22,3)	0,797
	Other	34/57	59,6	33/70	47,1	11,8 (5,6 to 28,2)	
Witnessed status	Witnessed	106/165	64,2	107/186	57,5	6,4 (-3,8 to 16,4)	0,150
	Unwitnessed	72/125	57,6	49/137	35,7	13,8 (6,2 to 21,1)	
Location	Outside home	67/94	71,2	65/102	63,7	8,3 (-4,8 to 20,9)	0,497
	At home	118/209	56,4	103/251	41,0	15,3 (6,1 to 24,1)	
Sex	Male	132/213	61,9	111/225	49,3	12,7 (3,4 to 21,7)	0,528
	Female	52/89	58,4	56/126	44,4	14 (0,4 to 26,8)	
Age group	<40 years	15/19	78,9	10/18	55,6	23,4 (-6,5 to 48,6)	0,889
	40-59 years	28/42	66,7	24/45	53,3	13,3 (-7,1 to 32,2)	
	60-79 years	79/126	62,7	65/136	48,1	14,6 (2,5 to 26)	
	>80 years	41/79	51,9	42/103	40,8	11,1 (-3,4 to 25,1)	
Response time	<6 min	59/79	74,7	46/88	52,3	22,4 (7,8 to 35,6)	0,093
	6-10 min	60/100	60,0	57/120	47,5	12,5 (-0,7 to 25)	
	>10 min	66/118	55,9	57/130	43,8	12,1 (-0,4 to 24)	

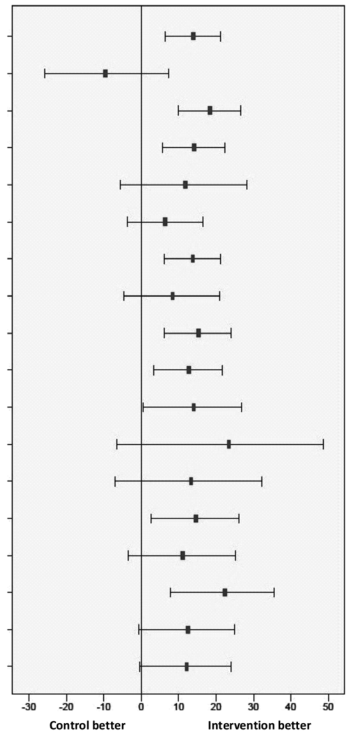


Table 4. Association between bystander CPR, intervention and baseline factors. Adjusted and unadjusted odds ratio (OR) from logistic regression

Treatment	Bystander CPR	Unadjusted OR (95% CI)	p-value	Adjusted OR 1 (95% CI)*	P-value	Adjusted OR 2 (95% CI)**	P-value
SMS	154/247 (62)	1,8(1,3-2,6)	0,000	1,7 (1,2-2,5)	0,004	na	na
Control	124/260 (48)						
Rhythm							
VF/VT	59/89 (66)	1,8 (1,1-2,9)	0,018	1,1 (0,7-2,0)	0,646	na	na
Asystole/PEA	219/418 (52)	REF		REF		REF	
Etiology							
Cardiac	230/418 (55)	1,0 (0,7-1,7)	0,851	1,0 (0,60-1,7)	0,960	1,0 (0,6-1,7)	0,995
Other	48/89 (54)	REF		REF		REF	
Witnessed status							
Witnessed	178/293 (61)	1,8 (1,2-2,5)	0,000	1,7 (1,2-2,5)	0,005	1,7 (1,1-2,5)	0,008
Unwitnessed	100/214 (47)	REF		REF		REF	
Location							
Outside home	99/143 (69)	2,3 (1,5-3,5)	0,000	2,1 (1,4-3,4)	0,001	2,2 (1,4-3,5)	0,001
At home	179/364 (49)	REF		REF		REF	
Sex							
Male	193/339 (57)	1,3 (0,9-1,9)	0,178	1,0 (0,6-1,5)	0,900	1,0 (0,7-1,5)	0,981
Female	85/168 (51)	REF		REF		REF	
Age group							
<40	22/32 (69)	2,5 (1,1-5,7)	0,025	2,9 (1,2-7,1)	0,019	2,7 (1,1-6,6)	0,031
40-59	44/74 (59)	1,7 (1,0-2,9)	0,068	1,6 (0,9-2,9)	0,151	1,5 (0,8-2,8)	0,171
60-79	137/240 (57)	1,5 (1,0-2,3)	0,039	1,5 (1,0-2,3)	0,062	1,5 (1,0-2,3)	0,076
>80	75/161 (47)	REF	REF	REF		REF	
Response time							
<6 min	85/130 (65)	1,9 (1,2-3,0)	0,006	1,9 (1,2-3,1)	0,009	1,9 (1,2-3,1)	0,007
6-10 min	96/183 (52)	1,1 (0,7-1,7)	0,633	1,0 (0,7-1,6)	0,864	1,1 (0,7-1,7)	0,684
>10 min	97/194 (50)	REF	REF	REF		REF	
Interction between intervention and rhythm							
VF/VT vs intervention	31/49 (63)	na	na	na	na	1,4 (0,7-2,9)	0,349
VF/VT vs control	28/40 (70)	na	na	na	na	2,0 (0,9-4,4)	0,082
Asystole/PEA vs intervention	123/198 (62)	na	na	na	na	2,1 (1,4-3,1)	0,000
Asystole/PEA vs control	96/220 (44)	na	na	na	na	REF	
Hosmer and Lemeshow test				0,197		0,917	

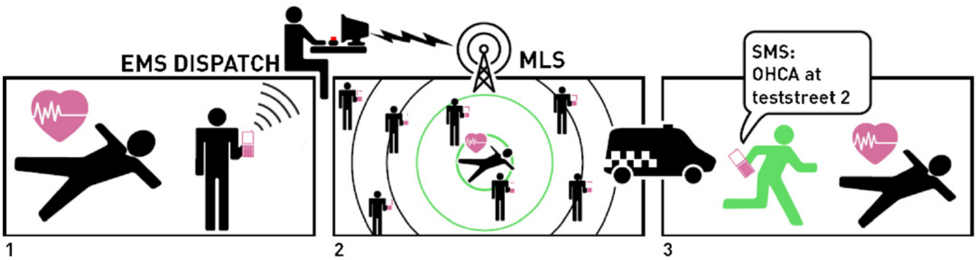
* Adjusted OR 1 = adjusted for primary rhythm, etiology, witnessed status, location, sex, age, response time. Analysis based 507 cases.

** Adjusted OR 2 = adjusted for etiology, witnessed status, location, sex, age, response time and interaction between intervention and rhythm. Analysis based on 507 cases

Table 5. SMS-lifesaver and survey data

	EMS treated OHCA (n=306)	All suspected OHCAs (n=861)
Cases with number of SMS-lifesavers located within 500m		
0	57	67
1-3	86	150
4-9	86	203
>10	77	135
SMS-lifesaver action		
1 or more SMS-lifesaver(s) *responding to SMS/Voice-alarms,* proportion of cases, % (n)	65% (n=199)	69 % (n=595)
SMS-lifesavers *reaching the scene,* proportion of cases, % (n)	59% (n=180)	60 % (n=520)
SMS-lifesavers *arriving at the scene prior to the EMS and first responders ;* proportion of cases, % (n)	23% (n=70)	23 % (n=202)
Proportion of cases in where SMS-lifesavers started CPR	13% n =40	na

Figure 1. Mobile positioning and logistics of the SMS-lifesaver service.



The geographical position (x,y co-ordinates) of all incoming emergency calls in Sweden can automatically be determined.

The dispatcher activates the Mobile Life Saver (MLS) in parallel with standard EMS if a OHCA is suspected. All users connected to the MLS are then positioned and matched with the position of the incoming call.

The users closest to the suspected OHCA are dispatched via a mobile phone text message (i.e SMS=short message system).

Figure 2. Flow of patients and primary outcome