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DUAL DISPATCH AND THE IMPORTANCE OF BYSTANDER CPR IN OUT-OF- HOSPITAL CARDIAC ARREST

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Number of saved lives in OHCA in Sweden 2016

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Dual dispatch and the importance of bystander CPR in out-of-hospital cardiac arrest

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■ I keep six honest serving-men
■ (They taught me all I knew);
■ Their names are What and Why and When
■ And How and Where and Who.
■ I send them over land and sea,
■ I send them east and west;
■ But after they have worked for me,
■ I give them all a rest.

The Elephant's Child
Rudyard Kipling 1902

Abstract

Background and aim

Survival after out-of-hospital cardiac arrest (OHCA) remains low. In Sweden in 2016, of 5312 cases reported to the Swedish Register of Cardiopulmonary Resuscitation (SRCR), only 577 (11%) survived to 30-days. The overall objective of the present work was to explore prehospital measures to increase survival for persons suffering OHCA, with special focus on alternative resources such as early bystander cardiopulmonary resuscitation (ByCPR), and dispatch of emergency medical services (EMS) in parallel with first responders (FRs) equipped with defibrillators performing basic life support.

Methods and results

Study I. A retrospective national register study covering 1990–2011 and including 30,381 witnessed OHCA. The primary aim was to evaluate the effect on survival if ByCPR was provided before arrival of EMS. 15,512 (51.1%) patients received ByCPR whereas 14,869 (48.9%) did not. Survival to 30-days was 10.5% in the ByCPR group vs. 4.0% in the no ByCPR group ($p < 0.001$).

Study II. A prospective national intervention study covering 2012–2014 and including 8698 OHCAs. In nine Swedish counties firefighters and/or police officers were trained in basic life support (BLS) and defibrillation and were dispatched at the same time as EMS in cases of suspected OHCA ($n = 3543$). This group was compared with a propensity-matched control group from twelve other counties where EMS only were dispatched ($n = 5155$). The final analytic sample consisted of 2786 matched pairs. The proportion of patients that survived to 30 days was 266/2786 (9.5%) in the intervention group vs. 214/2786 (7.7%) in the control group (conditional OR 1.27, 95% CI 1.05–1.54).

Study III. A prospective intervention study including 7200 witnessed OHCAs from the cohort in Study II. The primary aim was to evaluate 30-day survival in relation to time to treatment by means of cardiopulmonary resuscitation (CPR) and defibrillation by EMS or FRs. The cases were investigated as regards time for EMS arrival (< 8 minutes or > 8 minutes), and if ByCPR was provided or not. In the former group survival was 378/2016 (19.1%) compared with 542/5160 (10.7%) in the latter group ($p < 0.001$).

Study I. A qualitative interview study with 22 firefighters and police officers in Stockholm County participating in dual dispatch with EMS in cases of OHCA. In total 60 critical incidents (CIs) were identified concerning self-perceived OHCA situations. These were analyzed by using inductive content analysis. Three consecutive time sequences were found describing the cardiac arrest situation: *Preparedness*, *Managing the scene*, and *The aftermath*. The main findings were 1) Lack of information from the dispatch center caused frustration amongst first responders, 2) More thorough training was required in first aid and CPR, especially concerning rescue breaths. Education concerning psychological reactions amongst bystanders after an OHCA was requested, 3) Discussion after a mission with participating colleagues and superiors was deemed necessary, especially after tough cases.

Conclusions

Early ByCPR initiated before arrival of EMS more than doubled 30-day survival in cases of OHCA. This finding was consistent among all prespecified subgroups analyzed. Implementation of a national dual dispatch system of EMS and first responders in cases of OHCA providing CPR and potentially defibrillation, is associated with a shortened response time, more patients admitted to hospital alive and a moderate but significant increase in 30-day survival. The combination of reduced response times of EMS and FRs to less than eight minutes in cases of witnessed OHCA, and early ByCPR initiated before their arrival, can substantially improve 30-day survival, especially in cases with a shockable heart rhythm. When introducing dual dispatch of FRs as a second tier in cases of OHCA, CPR and hands-on AED training must be repeated annually to maintain CPR skills. Education in psychological reactions amongst bystanders should also be addressed, and team assessment offered after mission is important to avoid occupational stress.

Key words

automated external defibrillator, cardiopulmonary resuscitation, dual dispatch, defibrillation, emergency medical services, firefighters, first responders, out-of-hospital cardiac arrest, police officers, response time, survival

LIST OF SCIENTIFIC PAPERS

- I. **Hasselqvist-Ax I**, Riva G, Herlitz J, Rosenqvist M, Hollenberg J, Nordberg P, Ringh M, Jonsson M, Axelsson C, Lindqvist J, Karlsson T, Svensson L. Early cardiopulmonary resuscitation in out-of-hospital cardiac arrest. *N Engl J Med*. 2015. Jun 11;372(24):2307–15.
- II. **Hasselqvist-Ax I**, Nordberg P, Herlitz J, Svensson L, Jonsson M, Lindqvist J, Ringh M, Claesson A, Björklund J, Andersson J-O, Ericson C, Lindblad P, Engerström L, Rosenqvist M, Hollenberg J. Dispatch of firefighters and police officers in out-of-hospital cardiac arrest: A nationwide prospective cohort trial using propensity score analysis. *J Am Heart Assoc*. 2017;6:e005873.
- III. **Hasselqvist-Ax I**, Herlitz J, Jonsson M, Joelsson-Alm E, Ringh M, Claesson A, Nordberg P. The golden minutes where bystander cardiopulmonary resuscitation and first responder measures improve outcome in out-of-hospital cardiac arrest. *Manuscript*
- IV. **Hasselqvist-Ax I**, Nordberg P, Svensson L, Hollenberg J, Joelsson-Alm E. Experiences among firefighters and police officers of saving lives in out-of-hospital cardiac arrest in a dual dispatch programme. *Manuscript*

TABLE OF CONTENTS

Prelude.....	10
1 INTRODUCTION.....	11
1.1 Cardiac arrest.....	11
1.2 Incidence of OHCA.....	11
1.3 Patient characteristics.....	12
1.4 Cardiac rhythms in OHCA.....	12
1.5 Outcome.....	13
1.6 Uniform reporting of OHCA.....	15
1.7 Treatment in cardiac arrest: The Chain of survival.....	15
1.7.1 First link: Early recognition and call for help.....	16
1.7.2 Second link: Early CPR to buy time.....	17
1.7.3 Third link: Early defibrillation to restart the heart.....	19
1.7.4 Fourth link: Advanced cardiac life support and post resuscitation care to restore quality of life.....	21
2 AIMS.....	23
2.1 Specific aims.....	23
3 ETHICAL CONSIDERATIONS.....	24
4 METHODS.....	25
4.1 Data collection.....	25
4.1.1 The Swedish Registry of Cardiopulmonary Resuscitation.....	25
4.1.2 The EMCC database.....	26
4.1.3 The Swedish Civil Contingencies Agency database IDA.....	26
4.1.4 Police reporting of OHCA missions.....	26
4.1.5 Interviews.....	26
4.2 Overview of studies.....	27
4.2.1 Study I.....	28
4.2.2 Study II.....	28
4.2.3 Study III.....	29
4.2.4 Study IV.....	29
4.3 Dual dispatch.....	30
4.3.1 Dual dispatch in Stockholm County.....	30
4.3.2 Dual dispatch in other Swedish Counties.....	31
4.4 Methods of analysis.....	32
4.4.1 Study I.....	33
4.4.2 Study II.....	33
4.4.3 Study III.....	34
4.4.4 Study IV.....	34
5 RESULTS.....	35
5.1 Study I–Early bystander CPR.....	35
5.1.1 Main results.....	35
5.2 Study II–Saving more lives in Sweden.....	36

5.2.1	Main results	36
5.3	Study III–Bystander CPR and time to treatment by EMS or first responders	38
5.3.1	Main results	39
5.4	Study IV–Experiences of saving lives in cases of OHCA	40
5.4.2	Main findings	41
6	DISCUSSION	42
6.1	How can we increase rates of bystander CPR in the community?	42
6.2	Is the type of bystander performing cpr important for survival?	43
6.3	Does the type of CPR matter for survival?.....	43
6.4	How reliable is register data?.....	44
6.5	Dual dispatch and outcome: are we saving lives?	45
6.6	Police officers as a third tier in dual dispatch, is 1+1+1 really 3?	46
6.7	Study design–could we have performed a randomized trial instead?.....	46
6.8	Is a time limit of eight minutes to defibrillation realistic in OHCA?	47
6.9	What can we learn from the rescuers?	48
7	CONCLUSIONS	49
8	FUTURE PERSPECTIVES	50
9	SUMMARY IN SWEDISH.....	51
10	ACKNOWLEDGEMENTS AND GRANTS.....	53
11	REFERENCES	55
12	APPENDIX.....	67
12.1	Table 1A. Overview of First responder studies 1988–2016	67

LIST OF ABBREVIATIONS

AED	Automated External Defibrillator
ALS	Advanced Life Support
BLS	Basic Life Support
ByCPR	Bystander Cardiopulmonary Resuscitation
CA	Cardiac Arrest
CIT	Critical Incident Technique
CPC	Cerebral Performance Category
CPR	Cardiopulmonary Resuscitation
ECG	Electrocardiogram
EMCC	Emergency Medical Communication Center
EMD	Emergency Medical Dispatcher
EMS	Emergency Medical Services
FR	First Responder
ILCOR	International Committee on Resuscitation
OHCA	Out-of-Hospital Cardiac Arrest
PAD	Public Access Defibrillation
PROM	Patient Reported Outcome Measures
ROSC	Return of Spontaneous Circulation
SRCR	Swedish Register of Cardiopulmonary Resuscitation
T-CPR	Telephone-assisted Cardiopulmonary Resuscitation
VF	Ventricular Fibrillation
VT	Ventricular Tachycardia

PRELUDE

You are walking down the street on a dark, cold December evening; not many people are out and moving around. The only person you can see is a man in front of you, leaning heavily against a lamp post. Suddenly he drops to the ground, face down in the snow. Strange sounds are coming from him, like snoring. Is he ill or perhaps drunk? What will you do?

This man is suffering from a sudden cardiac arrest and here you can be the difference between life and death for him. You should turn him around and check 1) if he is conscious and 2) breathing normally, then you can decide if it is a cardiac arrest or some other condition. If the answer is no to both questions, you should call the dispatch center for help and immediately start cardiopulmonary resuscitation (CPR).

In Sweden over 3 million people have undergone CPR training over the years, and in our first study we sought to explore if early bystander CPR (ByCPR) had an impact on survival in cases of out-of-hospital cardiac arrest (OHCA). Our results confirmed earlier findings showing that survival increased more than twofold if bystander CPR started promptly without waiting for emergency medical services (EMS). The study we published is now one of the basic-reference articles in the European Resuscitation Council's guidelines (2015) on Adult Basic Life support.¹

Now back to your resuscitation efforts in the snowy street. You have worked on the victim for several minutes, giving him chest compressions. This is really tiring, but the dispatcher is supporting you via your cell phone and explains how to perform CPR. Sounds of sirens are now heard at a distance. All of a sudden firefighters are swarming all over the place to relieve you of your heavy responsibility alone with the victim. The fire brigade? Didn't you call for an ambulance?!

Several prehospital measures have been undertaken in recent decades to address the problem of low survival rates in cases of OHCA. To introduce a second tier of first responders, i.e. firefighters or police officers performing CPR and defibrillation and alerted simultaneously with the EMS, has been a clinical target and a research subject in several countries since the eighties. In 2005 a dual dispatch project commenced in Stockholm County, showing promising results regarding survival amongst OHCA victims.² Could we implement the same system and make it nationwide and thus increase survival? Now we know. This has been an exciting journey with the main purpose to hopefully save more lives in OHCA. This thesis is about that journey.

1 INTRODUCTION

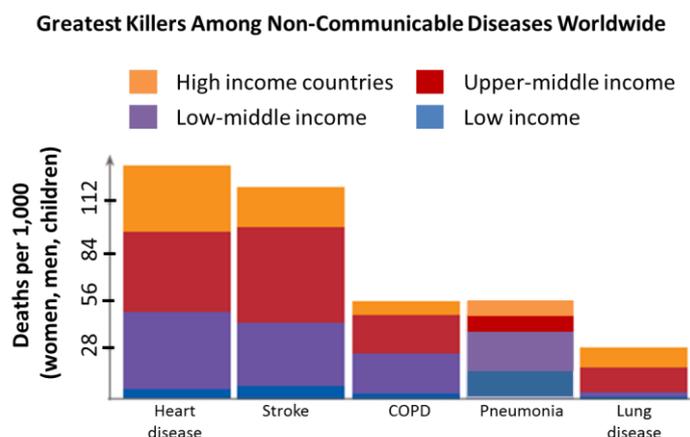
1.1 CARDIAC ARREST

Cardiac arrest (CA) is defined in the Utstein template as “The cessation of cardiac mechanical activity as confirmed by the absence of signs of circulation”.³ CA is also named *sudden cardiac arrest* (SCA), meaning it is abrupt and without previous warning signs. In the Framingham Heart study *sudden death* is described as when apparently healthy individuals collapses and dies in a matter of minutes with no other known cause but coronary heart disease.⁴ When a CA occurs blood flow to the heart and brain stops immediately and the victim loses consciousness within seconds. Death is imminent if no resuscitation is started promptly.

1.2 INCIDENCE OF OHCA

Out-of-hospital cardiac arrest in the western world is a major public-health concern, affecting almost 350,000 victims per year in Europe and 356,000 in the US.^{5,6} The overall survival rate is low; about 10 percent survive, or, more dramatically, 90% die. The incidence has been estimated to be approximately 37 cases per 100,000 person-years in Europe⁷, and 52 per 100,000 person-years in the US.⁸ Berdowski et al., in a systematic review, reported a median incidence estimate to be between 50 (Asia) to 71 (North America)/year per 100,000 individuals as regards EMS-treated OHCA.⁵ The incidence in Sweden varies between counties from the lowest reported, 30, to the highest, 72 per 100,000 person-years.⁹ As shown in Figure 1, heart diseases are responsible for the major death toll worldwide.

Figure 1. Deaths from non-communicable disease worldwide per 1000 persons



From “Utstein Meeting on Implementing Best Practices of EMS and Community Programmes to Improve Survival from OHCA: An International Call to Action. 2015.” Reprinted with permission from F. Lippert. COPD: chronic obstructive pulmonary disease

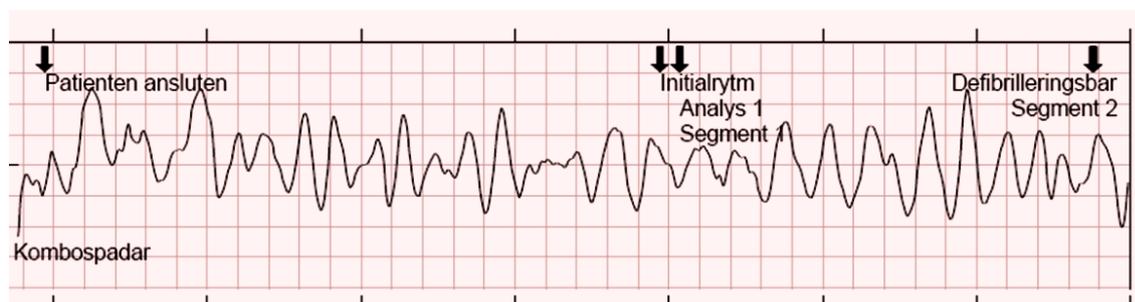
1.3 PATIENT CHARACTERISTICS

In Sweden patients suffering from OHCA are male in two thirds of all cases and the victims are about 70 years old. Approximately 60–70% of all reported cases in the Swedish Register of Cardiopulmonary Resuscitation (SRCR) have underlying cardiac ischemic heart disease etiology. Amongst non-cardiac causes are respiratory failure, pulmonary embolism, drug overdose, non-traumatic bleeding, sepsis, electrolyte abnormalities, intracranial processes and drowning.^{10, 11} Patients with a non-cardiac etiology have a less favorable outcome compared with those with cardiac causes.¹² Since 2015 the origin of cardiac arrest has been divided into medical and non-medical causes in the Utstein template.¹³ In about two thirds of cases cardiac arrest occurs at home. Approximately 54% are bystander-witnessed and 16% EMS crew-witnessed.¹⁴ Cases of OHCA amongst children (<18 years of age) are rare and they seldom have shockable ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) as the first recorded rhythm on their electrocardiogram (ECG). Instead, children most often suffer from asphyxia as a result of hypoperfusion or respiratory causes.^{15, 16}

1.4 CARDIAC RHYTHMS IN OHCA

Four cardiac rhythms characterize the initial phase of cardiac arrest. For practical reasons CAs are often described in terms of shockable and non-shockable rhythms. Amongst shockable rhythms are VT and VF (Figure 2), and in non-shockable rhythms, pulseless electrical activity (PEA) and asystole. The first rhythm in cases of OHCA refers to the first rhythm recorded by a monitor or when a defibrillator is attached to a patient in the intra-arrest phase or after cardiac arrest. VF or VT as the first monitored rhythm has been demonstrated to be the strongest independent predictor of survival in OHCA.¹⁷ The proportion of cases of VF/VT has progressively decreased in the recent decades, and thus the proportions of PEA and asystole in OHCA patients have increased.¹⁸ This phenomenon is seen worldwide (including Sweden) and the reason for this is not fully explained.

Figure 2. ECG pattern in shockable VF



In Sweden, the proportion of cases of VF recorded as the first ECG rhythm in witnessed OHCA with a cardiac cause, decreased from 49% in 1992 to 35% in 2016, and one can only speculate what the reasons for this decline may be.⁹ One factor might be the importance of early intervention. The EMS response time (time from dispatch to arrival at the victim) has gradually increased over the last 10 years, now reaching a median of 10 min in OHCA cases.⁹ If no ByCPR has started, the first and most vulnerable electric phase from the cardiac arrest to approximately four minutes, will change into the metabolic phase after about ten minutes. Thus transforming the VF/VT into a non-shockable asystole, with worse outcome.¹⁹ Furthermore, others have proposed that the well spread use of Implantable Cardioverter Defibrillators (ICDs) could be an explanation for declining incidence of VF, as well as the improved overall medication strategy for patients with heart diseases. For example, the wide use of beta blockers may also play an important role.^{20, 21}

1.5 OUTCOME

1.5.1.1 Outcome measures

The main outcome measures in cases of OHCA are:

- 1) Return of spontaneous circulation (ROSC) is when resuscitation has succeeded and palpable pulses are detected. Other signs of life are breathing, movements, coughing, or if systolic blood pressure can be measured.
- 2) Admitted alive to hospital with signs of ROSC.
- 3) Survival to hospital discharge.
- 4) Crude 30-day survival is the number of successfully resuscitated in OHCA divided by the total number of OHCA patients.
- 5) Neurological outcome status including survival after 30 days, 3 months or 6 months. For many years the Cerebral Performance Category (CPC) scale has been used,²² and also the modified Ranking Scale (mRS) for overall outcome, measuring the degree of disability in daily life activities. More sophisticated prognostic tools are used later in the process to test cognitive impairment in OHCA survivors.²³

1.5.1.2 Factors affecting outcome

In a meta-analysis of 142,000 OHCA patients over a period of 30 years the five key clinical criteria to predict survival were: 1) Witness status, if the CA was witnessed by a bystander, 2)

If the CA was EMS-witnessed, 3) First rhythm, shockable VF/VT as first rhythm, 4) By CPR before arrival of EMS, and 5) ROSC.²⁴ This is in line with the results of several other studies. On the other hand, other criteria can predict improved outcome, such as: female gender, younger age, non-shockable rhythm converting to a shockable rhythm, and agonal breathing.²⁵⁻²⁷

Overall, in Sweden today, 30-day survival rates are 11% for all rhythms and 33% for patients with VF as first rhythm.⁹ Furthermore, and most promising, the 30-day survival rate for all rhythms has almost doubled since the beginning of 2000.⁹ The reasons for this increased survival are most probably multifactorial, including mostly prehospital factors, but maybe also in-hospital reasons. As regards in-hospital factors there is conflicting evidence concerning the possible positive effects of various factors such as primary percutaneous coronary intervention (PCI), and hypothermia during hospital stay after OHCA. Several ongoing randomized studies will over the next 5–6 years hopefully give an answer to these questions.^{28, 29}

Differences in geography and demography (Sweden for example, is very sparsely populated outside the three largest urban areas) can play an important role in survival. Regional system factors such as available EMS may also be of importance for overall survival after OHCA.^{30, 31}

1.5.1.3 Neurological outcome

Neurological outcome after discharge can be prognosticated by using various instruments.³² These include the CPC scale and patient-reported outcome measures (PROMs).³³ The CPC scale is the oldest and most used instrument, ranging from 1–2 (good neurological outcome) to 5, which is certified brain dead.³⁴ CPC score measurement has over the last 5–10 years been under debate. Many researchers and clinicians argue that it is not precise enough to describe the cognitive situation of surviving patients'.³⁵ Differences in neurological functions between 1–2 and 3 are too wide. This is expressed in a systematic review by Moolaert exploring neurological outcome after CA, where the frequency of cognitive problems among survivors differed by 6%–100%.³⁶ The ability to return to work after surviving a CA has been used as a proxy of preserved neurological function in a Danish long-term study amongst 796 survivors to 30 days. Of patients with previous professional work, 76.6% returned to their former occupation.³⁷ Finally, health-related quality of life has been used in other studies to more deeply understand patients' outcomes. In one study, quality of life seemed to be similar for survivors, as for those who had not experienced an OHCA.³⁸

1.5.1.4 Socioeconomic factors

The importance of socioeconomic factors as regards the incidence of OHCA and subsequent survival has been studied in different settings. Low-income areas with populations of immigrants and/or ethnic minorities show a higher incidence of cardiovascular diseases and cardiac arrests. Bystanders in such communities are also more reluctant to intervene and start CPR.³⁹⁻⁴¹ This field of research, with implications for both medicine and sociology, has yet to be better explored and understood in Sweden and in other western countries.

1.6 UNIFORM REPORTING OF OHCA

1.6.1.1 The Utstein template

To assess and compare outcome in cases of OHCA between different regions and countries, a uniform system for reporting is of the highest importance. Therefore, this was the goal in the first meeting with leading researchers in the field, which took place at Utstein abbey in Norway in 1990.³⁴ The Utstein template created at the meeting has since then been revised twice (2004, 2014) and, further, provides consensus reporting guidelines for resuscitation.^{3, 13} This template is usually referred to in scientific articles as reporting in “Utstein-style”. An ambitious European register including reports from 27 different European nations, EuReCa ONE, concerned 10,682 cases of OHCA basically using this template. The overall purpose of this European register is to detect differences between countries and possibly take appropriate action for increased survival at both a European and a national level. The first EuReCa report shows there are still considerable differences between countries concerning reporting and outcome in OHCA.⁴²

1.7 TREATMENT IN CARDIAC ARREST: THE CHAIN OF SURVIVAL



Figure 3. The Chain of survival

1.7.1 First link: Early recognition and call for help to prevent cardiac arrest

The Chain of survival represents different step-by-step interventions to be taken before and after a CA occurs to optimize the chances of survival.^{43, 44} Maybe the most important in this Chain of survival is the first link, to understand and call for help when persistent chest pain occurs, thus enabling EMS to arrive before a possible CA take place.⁴⁵

Often no prodromes have preceded the CA. The problem for bystanders is therefore to determine if the victim has a CA or not. This is most often the circumstance if the witness is untrained in CPR. An immediate examination must therefore be performed: is the patient unconscious with a respiratory arrest? Then as soon as possible a rapid call has to be made to the emergency medical communication center (EMCC) and CPR has to be started immediately, as described in the American and European guidelines for resuscitation.^{46, 47} A delay from collapse to call has been demonstrated to decrease the chance of survival in witnessed cases of OHCA. In an observational study 30-day survival was 7.5% if the call was made within 2 min, compared with 1.2% if the delay was >8 min after collapse.⁴⁸

1.7.1.1 Telephone-assisted CPR (T-CPR)

At the dispatch center, when CA is suspected, the emergency medical dispatcher (EMD) is instructed to offer the caller guidance in T-CPR. This action seems to improve survival.⁴⁹ However, this has previously been found to be offered to only a small fraction of bystanders.⁵⁰ The reasons for this are reported to be a caller's unwillingness to participate, a caller disconnecting the phone, or a bad emotional state of the caller, for example.⁵¹ One of the main obstacles preventing lay-persons from performing T-CPR is the fact that instructions are difficult to explain, and therefore the performance of ventilation by the bystander is poor and time consuming. To explain maneuvers to open the airway and give rescue breaths during a stressful situation is complicated. Therefore T-CPR instructions were altered in the resuscitation guidelines in 2010 to chest compressions only without rescue breathing.⁵² This was implemented after the publication of two randomized controlled studies showing no difference in 30-day survival between groups with standard CPR vs. chest compression only.^{53, 54} Furthermore, increased survival was found in chest compression only groups compared with standard CPR in a meta-analysis of three randomized studies (RR 1.22, 95% CI 1.01–1.47).⁵⁵

1.7.1.2 The importance of identifying agonal breathing

Agonal breathing (gaspings) is induced by cerebral ischemia and is characterized by an abnormal breathing pattern with slow, shallow and irregular breaths in the first minutes after CA. As stated above (Section 1.5.1.2), agonal breathing is a predictor of increased survival in OHCA, and its occurrence is reported to be between 33% to 60% in cases of OHCA.^{27, 56, 57} This abnormal breathing can persist for several minutes, thus making it difficult for both the witness and the EMD to assess if it is a CA or not. Most commonly it is depending on the often inconsistent description from the caller. Several investigators have pointed out the importance of highlighting this dilemma and to further train dispatchers to better and more rapidly recognize agonal breathing. This has been shown to improve the rate of T-CPR offered by dispatchers.^{58, 59} The importance of dispatchers to identify a CA early is demonstrated in a study from Amsterdam. When a dispatcher identified a CA, 3-month survival was 14%, versus 5% if not identified ($p= 0.04$).⁶⁰

1.7.2 Second link: Early CPR to buy time

The second link in the chain of survival refers to any CPR performed before arrival of EMS or first responders (FRs). If ByCPR is provided, the time for favorable rhythms (VF/VT) can be prolonged—doubled or even tripled.⁶¹ For every minute without treatment (CPR, defibrillation and definitive care), the chance of survival declines by 5.5% per minute.⁶²

1.7.2.1 Early bystander CPR

Early CPR compared with no or delayed CPR, has proved in several register studies to double or triple 30-day survival in cases of OHCA.⁶²⁻⁶⁵ This was also the case in Study I within this Ph.D. project. We demonstrated that if ByCPR was given before arrival of EMS, survival was 10.5% as compared with 4.0% ($p<0.0001$) in the no-CPR group. This was found in a cohort of 30,391 witnessed OHCAs in Sweden in 1990–2011.⁶⁶

The proportion of ByCPR differs greatly between countries and regions, varying from 16% in Germany,⁶⁷ to 31% in the US⁶⁸, and 73% in Stavanger, Norway.⁶⁹ Data from SRCR 2016 shows that 75% of cases of witnessed OHCAs in Sweden received ByCPR before arrival of EMS.⁹ In Denmark the proportion of bystander CPR increased from 21.1% to 44.9% in 2001–2009, due to mandatory CPR training in connection with taking a drivers license, introduction of health care personnel at EMCCs providing T-CPR instructions, and mandatory CPR courses in elementary schools.⁷⁰

1.7.2.2 *High-quality CPR (HQ CPR)*

High-quality CPR involves a chest compression depth of at least 5 cm in adults, at a rate of 100–120 compressions/minute, a compression–ventilation ratio of 30:2, and minimization of interruptions.¹ The quality of CPR provided may be of importance for outcome, but this is still to be proved. However, there are indirect proofs and indications of the importance of HQ CPR. Previous studies have shown that if CPR is performed by a person not skilled in or untrained in CPR, the outcome is similar to that if no CPR at all is performed.⁷¹ This stresses the importance of repeated, annual training in CPR, since retention is short.⁷² Another method to improve CPR quality is by using devices providing real-time prompts, and demonstrating feed-back in chest compression rate, recoil, depth and/or ventilation. These devices can be used by the rescuer, and this is also emphasized for health-care personnel in resuscitation guidelines 2015.⁷³

1.7.2.3 *Simplified CPR*

To simplify intervention for bystanders, chest compression-only CPR, instead of chest compression and rescue breathing, is recommended for lay-persons receiving T-CPR instructions, and for lay-persons in an randomized controlled trial addressing this issue has recently started in Sweden, where bystanders with skills in CPR are being randomized by dispatchers to chest compressions only (intervention group) or standard CPR (control group), the TANGO2 study (ClinicalTrials.gov, NCT02401633).

1.7.2.4 *Hands-off time*

Hands-off time is also a part of CPR quality and represents the time when no chest compressions at all are performed. The first and most important publications in regard to hands-off periods were from Wik et al. in 2005. They found that in 48% of CPR time EMS personnel were occupied with other tasks. EMS personnel were more focused on the Advanced Cardiac Life Support (ACLS) algorithm, such as administering drugs, rhythm-recognition and handling the airway, than actually performing CPR.⁷⁴ An increased chest compression fraction (CCF), i.e. time providing chest compressions, can contribute to a higher ROSC rate and thereby increased survival.^{75, 76}

A solution to this hands-off problem, especially in ambulances, is the use of mechanical chest-compression devices (LUCAS™, AutoPulse™ Corpuls CPR™), enabling high-quality continuous chest compressions even during transportation. Two large randomized studies comparing qualitative manual CPR vs. mechanical chest compressions in pre-hospital settings were however, neutral as regards survival to hospital discharge.^{77, 78}

1.7.2.5 Recruitment of bystanders

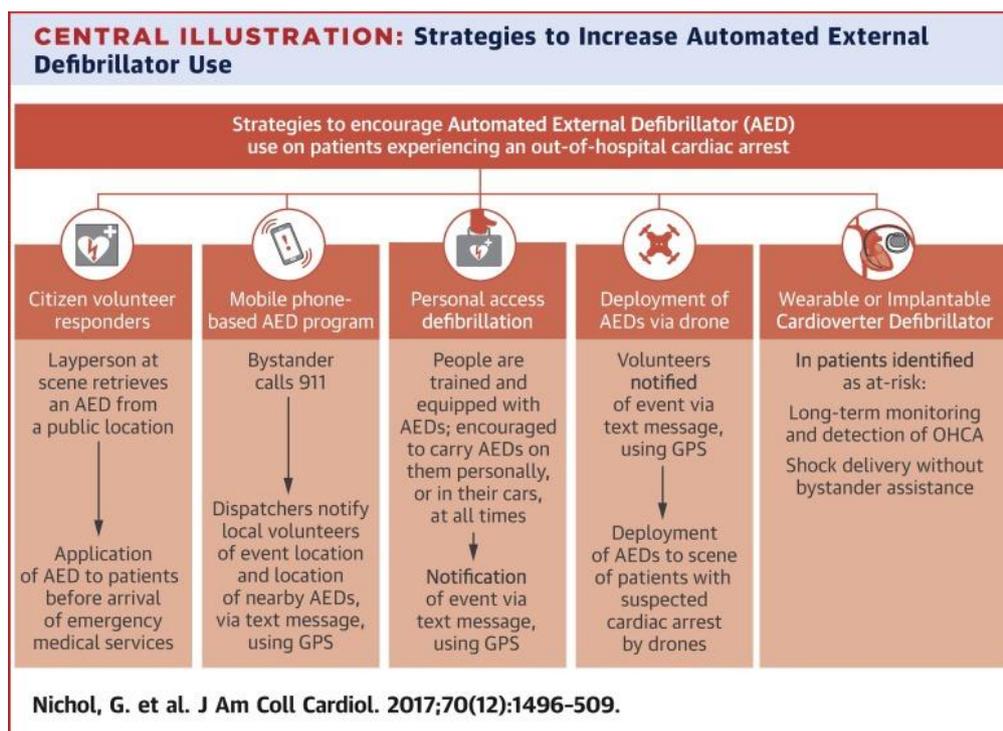
Not only education of the population in CPR but also recruitment of bystanders to go to aid of victims seem to be the key issues to increase survival in OHCA. Different approaches and strategies have therefore been undertaken. A promising method to increase the proportion of ByCPR is to recruit trained lay rescuers by using cell-phone technology. This can be achieved by sending a short message service (SMS) text from EMCCs in cases of OHCA. If the volunteer is in the vicinity of 500 meters from the victim, the phone is detected by triangulation from nearby mobile towers and alerted. This method has proven to increase ByCPR by 30% (62% in an intervention group of lay rescuers alerted by SMS, compared with 48% in control group).⁷⁹ Other initiatives also using mobile phone technology to activate bystanders are being carried out in the Netherlands where lay rescuers are being alerted by SMS using the rescuer's post-code number.⁸⁰

1.7.3 Third link: Early defibrillation to restart the heart

During the last 15–20 years the development of small, user-friendly automated external defibrillators (AEDs) has opened up for professionals such as firefighters, police officers, and security guards to act as FRs and to be part of an early defibrillation program. This treatment has traditionally been administered by EMS personnel.

Two factors are of vital importance for survival after OHCA: time from collapse to start of CPR, and time from collapse to defibrillation. Defibrillation is necessary to restore a regular rhythm within the ventricular fibrillating heart. The rescuer attaches self-adhesive electrodes to the patients' chest, the AED analyzes the ECG pattern and advises a shock of 150–200 Joules for adults if a shockable rhythm is present. If defibrillation is administered within three minutes from collapse, survival rates have been reported to be as high as 74% in witnessed cases of CA with VF.⁸¹ Similar results have been reported when defibrillation has been performed by flight attendants in commercial aircraft, showing 40% survival to discharge after CA.⁸² In Sweden 70% survived to 30 days if a public AED were used by lay bystanders.⁸³ High survival rates were also shown in a meta-analysis of 41 public-access defibrillation (PAD) studies comparing two groups: lay first responders (non-dispatched), and dispatched FRs (police/fire fighters). The highest survival rate to hospital discharge was seen in the lay group compared with the FR group (53% vs. 29%).⁸⁴

Figure 4. Strategies to increase AED use



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Different approaches regarding the use of AEDs have been undertaken with the aim of reaching CA victims earlier (Figure 4).⁸⁵ However, one important strategy is missing in the illustration above—an FR programme with early CPR and early defibrillation before arrival of EMS. This is addressed in the present work.

One of the main obstacles to start early CPR and to defibrillate the victim is that most cardiac arrests occur at home and are thereby unavailable for rapid defibrillation. In the HAT study researchers tried to address this issue. About 7000 patients with earlier myocardial infarction and an elevated risk of CA (low ejection fraction) were included and randomized to either a control group with standard procedures for rescuers (calling the EMCC and performing CPR), or to an intervention group who received a “home AED” and instructions to spouse or other family members to use the AED first, then call the EMCC and start CPR. The results, surprisingly, showed no difference in overall mortality between the two groups.⁸⁶

Other initiatives to achieve early defibrillation in public places and in the patients’ homes have been to provide so-called first responders, i.e. police officers or firefighters with AEDs, alerting them by dispatchers in parallel with EMS. They have more often been found to be faster than the EMS, and this has improved survival and reduced response time.^{2, 87-89} A study with conflicting results is from the Amsterdam area including both firefighters and police officers using AEDs, where no increased rate of survival to discharge from hospital was

found, although the rates of ROSC and admission to hospital improved.⁹⁰ One reason for this may be that Amsterdam started at a very high level of survival compared with other places and previous studies. Therefore, to show an additional effect by using FRs were more difficult.

When placing AEDs in public places, the frequency and incidence of cardiac arrests, and population size, play important roles when planning PAD programmes. In the American and European guidelines on public-access defibrillation it is recommended that AEDs be placed where there is a great probability that a witnessed CA will occur at a rate of at least one per five years, for example in airports, shopping centers and sport facilities.^{1,91} Similar recommendations have been adopted by the Swedish Resuscitation Council. Further research is necessary to more accurately match AEDs with high-risk areas as regards OHCA, instead of spreading them randomly in the community.⁹²⁻⁹⁴

1.7.4 Fourth link: Advanced cardiac life support and post resuscitation care to restore quality of life

The fourth link includes interventions provided by EMS in advanced cardiac life support (ACLS), such as intravenous/intraosseal drug treatment, endotracheal intubation or insertion of a laryngeal mask airway, and manual defibrillation. If ROSC has been achieved but the patient is still comatose when arriving at hospital, a treatment algorithm for post-resuscitation care is nowadays available in the resuscitation guidelines since 2015.³² When discussing the post-resuscitation phase, guidelines and clinicians basically focus on three main aspects of post-resuscitation care, namely:

1. Targeted temperature management (TTM) – more often known as cooling or therapeutic hypothermia.
2. Direct or immediate coronary angiography in patients with an ECG presenting with no signs of ST-segment elevation myocardial infarction (STEMI). In these cases, the receiving hospital must be organized 24/7 to perform an acute angiogram, with the possibility of performing percutaneous coronary intervention (PCI).
3. Prognostication in all individual cases before withdrawal of care. Furthermore, it is also stated that overall high-quality care during the hospital stay should also be focused on, for example on regionalized care in a more specialized “cardiac arrest center”. Post-arrest care should be driven towards “cardiac arrest centers” in the same manner as the care given to patients presenting with trauma, stroke, and primary PCI for STEMI.

Amongst new insights in the field of research within this group of patients are cooling strategies (both pre- and in-hospital), the effectiveness of new neuroprotective drugs after CA, extracorporeal cardiopulmonary resuscitation (E-CPR) as a treatment strategy for OHCA patients in persistent VF, and also urgent vs. delayed coronary angiography for patients without ST-elevation on the ECG.⁹⁵ However, the fourth link is not within the scope of this thesis.

2 AIMS

The overall aim was to explore various prehospital factors and their impact on survival in persons suffering from out-of-hospital cardiac arrest, with special focus on early bystander CPR and the impact of dispatching firefighters and/or police officers equipped with AEDs simultaneously with EMS on a national level. The importance of time to treatment by EMS and first responders was also taken into consideration.

2.1 SPECIFIC AIMS

Study I

To examine whether bystander CPR provided before arrival of EMS was associated with an increase in 30-day survival in a population of witnessed cases of OHCA. A secondary aim was to assess the association between estimated time from collapse to start of CPR, and 30-day survival.

Study II

To evaluate 30-day survival in cases of OHCA at a national level after implementing a dual dispatch system of first responders trained in BLS and equipped with AEDs in nine Swedish Counties (intervention group), in comparison with dispatch of EMS only in twelve Counties in Sweden (control group). Secondary aims were the proportion of patients admitted alive to hospital, and time from emergency call to arrival of FRs or EMS.

Study III

To evaluate and quantify the relationship between time to treatment by EMS or FRs, and ByCPR initiated prior to their arrival, and 30-day survival in cases of OHCA. A secondary aim was to assess the proportion of patients admitted alive to hospital in relation to time to treatment with CPR and defibrillation.

Study IV

To explore firefighters' and police officers' experiences of saving lives in cases OHCA in a dual dispatch programme with EMS.

3 ETHICAL CONSIDERATIONS

Persons suffering from OHCA are unable to give their approval to participate in clinical trials, or consider registration in a national register. Informed written or oral consent can thus only be granted by relatives present at the occasion or afterwards if the person survives. At that time the treatment has in most cases already been administered, and most often there is no option to say “no”. Introducing new medications or technical methods in the prehospital setting concerning this patient group therefore raises ethical questions regarding autonomy, and has been debated in Sweden and other countries for many years.

Approximately 90% of the OHCA population die at the scene, and over time many prehospital initiatives to increase survival seem to have had only minor significance. Ethical aspects of benefit for the whole future OHCA population can be in contrast to protection of rights off the individual, which could be considered a utilitarian approach.

A governmental missive from the Ministry of Health and Social Affairs was published in 2015 (SOU 2015:80)⁹⁶ about care for, and research on patients with disorders of consciousness,⁹⁷ but to date no proposition been presented to the Swedish Parliament concerning the matter.

In this work, we used the SRCR as a principal database in Studies I–III. Data on outcomes are described only at group level, not at individual level. Aspects of research on humans have been taken into account, following medical ethical principles in the World Medical Association Declaration of Helsinki 1964, revised in 2013.⁹⁸ In this amendment, in paragraphs 28–30 in the Declaration concerning research subjects incapable of giving informed consent, it is now stated that permission from a legally authorized representative must be obtained, i.e. a research ethics committee.

Study I was approved by the Regional Ethics Review Board in Gothenburg, giving general permission for research using OHCA data from the SRCR (registration number S 394–00). In the past three years all register extractions have required individual ethics approval. Studies II and III were approved by the Regional Ethics Review Board in Gothenburg (registration number 242–11).

In the interview study (Study IV) all informants received both written and oral information about the study and the possibility to withdraw their participation without any reprisal. To narrate sensitive events about an OHCA situation could bring back agonizing feelings, especially if one’s own performance was not satisfactory, or the outcome turned out to be

bad. This was considered a risk for the participants. However, no person renounced participation. Study IV was approved by the Regional Ethics Review Board in Stockholm (registration number 2015/1091–31/5).

Studies II and III are classified as interventional cohort studies and were therefore registered at clinicaltrials.gov (registration number NCT02184468).

4 METHODS

4.1 DATA COLLECTION

The data sources used in this work are described in this section. In Studies I–III the SRCR was used, and in Studies II–III also the EMCC and the Swedish Civil Contingencies Agency databases described below. A questionnaire was used in Study IV, containing six questions about the cardiac arrest situation and also demographic questions.

4.1.1 The Swedish Registry of Cardiopulmonary Resuscitation

Data used in Studies I–III was retrieved from the SRCR. The register is a national quality register founded in 1990 for OHCA and in 2005 also opened for patients with in-hospital cardiac arrest (IHCA). All EMS organizations in Sweden report OHCA variables according to the Utstein template online since 2009. Before this, case report forms were filled in manually by EMS and sent to the registry. Included are all patients where bystanders or EMS personnel have started any form of resuscitation, i.e. basic life support (BLS) or advanced life support (ALS). Excluded are cases with obvious signs of death (rigor mortis or lividity), where the EMS crew assesses resuscitation efforts as futile. At present, 87,811 patients are included, representing all ages.⁹

Outcome has been reported historically as 30-day survival. A CPC score between 1 and 5 has been reported for all survivors over the past five years, where CPC 1 is good cerebral performance, and CPC 5 is certified brain death.³⁴ Registration of PROMs for quality controls concerning health related quality of life among survivors has been performed retrospectively since 2013.

Audits and validation of prehospital and hospital register data compared with data exported from local ambulance registers is executed by a quality group. The information is explored to identify missing cases. Overall, it appears that 25% of all CA are missed by EMS. The majority of these cases are reported afterwards by the quality group. This procedure has previously been described by Strömsöe et al.⁹⁹

4.1.2 The EMCC database

The national Swedish dispatch center, SOS Alarm AB, answers all incoming emergency calls to the unique number 112 for EMS, and fire- and police services. Today there are 13 dispatch centers in Sweden handling a total of 2800 medical cases every day.¹⁰⁰ In Studies II and III the time of the incoming emergency call from a bystander, time of dispatch of EMS and arrival time at the scene were obtained digitally from the data-handling system QlikView®. The exact location of the victim's address was determined via *x* and *y* coordinates from a global positioning system (GPS). A specific case number and time stamp are created for each and every event and this is done automatically when the dispatcher receives the phone call. This unique number was crucial for the study in finding all cases, both missing and reported within this study.

4.1.3 The Swedish Civil Contingencies Agency database IDA

The Swedish Civil Contingencies Agency (MSB) is a governmental agency responsible for civil defense and protection, emergency management and public safety under the Ministry of Justice.¹⁰¹ In Studies II and III data from the statistics and analysis tool IDA was retrieved for all fire-brigade missions concerning OHCA alarms during 2012–2014. Date of event, which specific fire brigade reported the case, time from dispatch to arrival time at the scene, and the unique time stamp created by the EMCC were collected to enable linkage between databases.

4.1.4 Police reporting of OHCA missions

The general police reporting register is not built to fully report health-system issues. Therefore there have been some difficulties to obtain full and/or correct OHCA data after police officers have been involved as FRs. The police reporting system STORM does not have word codes such as CPR, cardiac arrest or defibrillation. Police officers in Halland County therefore reported OHCA cases on line in an external database created especially for Study II, located at the Centre of Registers in Western Sweden.¹⁰² Police attendance in Stockholm County was reported on line or through a case report form sent to the investigators. No digital registration of arrival time, time to CPR etc. was reported, only estimated times. The specific case number created by the EMCC was the link between the registers.

4.1.5 Interviews

The interview guide used in Study IV consisted of six open-ended questions designed in alignment with the critical incident technique described by Flanagan.¹⁰³ All the interviews were conducted by the first author and commenced with 10 demographic questions covering

aspects such as age, professional experience, attendance at CPR alarms, most recent CPR training, type of CPR training, experiences of rescue breaths, chest compressions, defibrillation and any additional health-care education (Article IV, Table 2). The questionnaire was tested in a pilot interview with a FR and no changes were made thereafter. All interviews were recorded with a digital voice recorder (Olympus™ VN–7800PC) and transcribed verbatim for further analysis.

4.2 OVERVIEW OF STUDIES

An overview of the studies included in this thesis is presented in Table 1. Both quantitative and qualitative approaches have been used, depending on aims.

Table 1. Overview of Studies I–IV

	Study I	Study II	Study III	Study IV
Design	Retrospective observational study	Prospective national intervention study	Prospective national intervention study	Interview study using qualitative content analysis
Study period	Jan 1, 1990–Dec 31, 2011	Jan 1, 2012–Dec 31, 2014	Jan 1, 2012–Dec 31, 2014	Feb 12, 2015–Dec 16, 2016
Included (n)	30,381 bystander-witnessed OHCA in Sweden	8,698 OHCA in Sweden	7,200 bystander-witnessed OHCA in Sweden	22 firefighters and police officers in Stockholm County
Database	SRCR	SRCR EMCC IDA	SRCR EMCC IDA	N/A
Exposure	ByCPR provided or not before arrival of EMS	Treatment by FRs with CPR and potentially defibrillation	Time to treatment by EMS or FRs (<8min or >8 min) and if ByCPR was provided	N/A
Outcomes	30-day survival, Time from collapse to start of CPR and survival	30-day survival, Patients admitted alive to hospital, Time from call to arrival of FRs or EMS	30-day survival in relation to time to treatment with CPR/defib. Patients admitted alive to hospital	N/A

ByCPR:bystander cardiopulmonary resuscitation; DNAR; do not attempt resuscitation; EMCC:emergency medical communication centre; EMS:emergency medical services; FRs:first responders; OHCA:out-of-hospital cardiac arrest; IDA:Swedish civil contingencies agency database; SRCR:Swedish register of cardiopulmonary resuscitation

4.2.1 Study I

Study design

Retrospective observational study based on outcome data from the SRCR.

Study population

Bystander-witnessed OHCA recorded from January 1st, 1990 to December 31st, 2011 where resuscitation was started by EMS or bystanders. Excluded were non-witnessed and EMS crew-witnessed cases. This resulted in a study population of 30,381 patients.

Exposure

Exposure was whether or not ByCPR was initiated before arrival of EMS.

Outcomes

The primary outcome was 30-day survival. We also investigated the association between estimated time from collapse to start of CPR, and 30-day survival.

4.2.2 Study II

Study design

A prospective intervention design was used. The study with the acronym “Saving More lives in Sweden” (SAMS), was conducted in nine Swedish counties in which a dual dispatch system of firefighters and/or police officers trained in BLS and equipped with AEDs in cases of suspected OHCA was used (intervention group), compared with a contemporary and propensity-matched cohort in twelve other Swedish Counties where no dual dispatch took place (control group). The intervention counties were enrolled stepwise during the study period (Study II, Figure 2). In the counties of Stockholm and Södermanland dual dispatch of firefighters and EMS was initiated already in 2005 and 2008 respectively. In Stockholm County police officers were dispatched as a third tier in conjunction with EMS and firefighters. In the county of Halland the term “dual dispatch” was used when police officers and EMS were dispatched.

Study population

All OHCA registered in the SRCR independent of witnessed status, cardiac rhythm or morbidity, during January 1st, 2012–December 31st, 2014 where EMS or bystanders had started resuscitation. Exclusion criteria were children < 8 years, EMS crew-witnessed cases, obvious signs of death and persons with do not attempt resuscitation (DNAR) orders, leaving a study population of 8,698 cases as a basis for matching.

Exposure

The main exposure was treatment by first responders dispatched to perform CPR and possible defibrillation with an AED.

Outcomes

The primary outcome was 30-day survival. Secondary outcomes were the proportion of patients admitted alive to hospital, and time interval from emergency call to the EMCC to arrival of EMS or FRs.

4.2.3 Study III

Study design

A prospective intervention study. Study design is described in Study II (Section 4.2.2).

Study population

Witnessed OHCA cases included in the SRCR independent of cardiac rhythm or morbidity, where EMS or bystanders had started resuscitation in January 1st, 2012–December 31st 2014. Excluded were children <8 years, EMS crew-witnessed cases, obvious signs of death and persons with Do Not Attempt Resuscitation orders. In total, 7,200 cases were included.

Exposure

ByCPR provided or not in cases of OHCA before arrival of EMS or FRs and the correlation with time to treatment, defined as arrival time of EMS <8 minutes or >8 minutes.

Outcomes

The primary outcome was 30-day survival in relation to time to treatment with CPR and defibrillation by EMS or FRs. A secondary outcome was the proportion of patients admitted alive to hospital in relation to time to treatment with CPR and defibrillation.

4.2.4 Study IV

Study design

An interview study involving narrated cardiac arrest situations analyzed by a critical incident technique (CIT) and inductive content analysis, conducted in June 8th, 2016–December 13th, 2016.

Study population

The sample consisted of 22 firefighters and police officers participating in a dual dispatch system with EMS in cases of suspected OHCA in the County of Stockholm.

4.3 DUAL DISPATCH

4.3.1 Dual dispatch in Stockholm County

When a suspected OHCA occurs and a bystander calls the alarm number 112, the EMCC is obliged to answer the call within eight seconds (median) according to governmental agreements. Identification of cardiac arrest by using the Swedish Medical Index¹⁰⁴ takes place immediately where the main dispatch code words are unconscious adult, unresponsive and not breathing normally (Table 2).

Table 2. Dispatch codes for suspected cardiac arrest at the EMCC

Unconscious adult – Unresponsive and not breathing normally
Unconscious adult – Ongoing cardiopulmonary resuscitation
Unconscious adult - Case of serious illness
Unconscious adult – Unresponsive and no breathing
Unconscious adult – Ongoing Telephone-CPR
Unconscious adult – Unresponsive
Unconscious child – Unresponsive and not breathing normally
Unconscious child – Ongoing cardiopulmonary resuscitation
Unconscious child – Case of serious illness
Unconscious child – Unresponsive and no breathing
Unconscious child – Unresponsive
Unconscious child – Ongoing Telephone-CPR
Seizure – Unresponsive
Difficulty in breathing – Unresponsive
Diabetes – Unresponsive
Drowning – Unresponsive and not breathing normally
Suspected suicide – Unresponsive and not breathing normally

Two questions are found to be of vital importance to determine classification as CA^{60, 105}:

- 1) Is the person conscious?
- 2) Is the person breathing normally?

Approximately 70–76% of all calls to the EMCC concerning suspected OHCA are classified as true cardiac arrests, i.e. they can retrospectively be found in the SRCR.¹⁰⁶

The nearest available ambulance is dispatched, staffed with one specialist nurse and one emergency medical technician (EMT). A second support ambulance is also always summoned, manned with a nurse anesthetist and an EMT. A medical advisor (doctor) can be reached by telephone via the EMCC, and also directly through attendance of a physician-staffed vehicle. This is usually the case in more complicated emergencies such as those involving children, and cases of major trauma. In cases of dual dispatch the call is transferred

simultaneously by the EMCC to the Rescue Dispatch Center for the fire brigade by way of a computer mediated alarm and a fire engine with up to five firefighters is dispatched.

To reach the regional Police Communication Center in Stockholm, a telephone call has to be made from the EMCC after dispatching of EMS and the fire brigade, which potentially delays police dispatch substantially. The police patrols are therefore the last units in the alarm chain to receive the call out. Much effort has been undertaken by the researchers to improve the response time for the police, but with only a little progress so far. The most effective method concerning response times appears to be invitation of police officers to use a mobile phone application, “SMS Lifesaver” and thereby receive an alert when an OHCA occurs in the vicinity.¹⁰⁷

Dispatch of police patrols in “dual dispatch OHCA alarms” is not mandatory and can be regarded as an extra resource if available. In a survey in Stockholm County, sampling police presence in OHCA alarms over three weeks in 2015 and 2016, their presence varied from 20/31 (65%) to 21/26 (81%) (Svensson, Leif. Unpublished data).

4.3.2 Dual dispatch in other Swedish Counties

Handling of emergency calls at EMCCs is similar throughout the whole country. Because of scarce ambulance coverage in more rural areas, usually only one ambulance is dispatched, with no back-up vehicle for extra assistance. This is the case in many rural districts in Sweden. Therefore the fire brigades have over the years played an important role for the population in more sparsely populated areas in cases of all sorts of emergencies including OHCA.

4.3.2.1 Dispatch of fire fighters

All major cities in Sweden have “full-time stations”, meaning that the fire station is staffed with firefighters around the clock. However, approximately 68% of the firefighters in Sweden work part time (“part-time stations”), meaning they hold another civil profession and are alerted to the fire station when needed.¹⁰¹ This is often the case in more rural and sparsely populated areas. In such stations usually 6–8 minutes pass before the fire engine can leave the station after call out. In other counties a fast single-person unit with one team leader/incident commander from the fire brigade providing CPR and defibrillation is called out as first responder. This organization and model can considerably save response time to the victim.

4.3.2.2 *In waiting for the ambulance (IVPA)*

When an ambulance sent by the dispatcher is assessed to be more than 10–15 minutes away from an emergency, the dispatcher can request a fire engine as support. This is called “In waiting for the ambulance” with the acronym IVPA. The firefighters’ mission is then to be ready to: provide first aid, administer oxygen, immobilize trauma patients, support relatives/bystanders, and to perform BLS and defibrillation if necessary. In Studies II and III these IVPA alarms were not excluded. However, it is important to remember that this kind of dispatch is not done simultaneously with dispatch of EMS (Study II, Table II, FRs first on scene).

IVPA has been a reality for over 15 years in Sweden and the system is regulated by the National Board of Health and Welfare, and administered by agreements between the municipalities and the County Councils.¹⁰⁸ Over the years there has been an annual increase in medical missions for fire brigades, in 2015 there were 13,600 reported IVPA alarms in Sweden.¹⁰¹ Lack of ambulance resources is the most probable reason for this phenomenon.

4.4 METHODS OF ANALYSIS

Statistical methods used in this work are shown in Table 3. Values of p below 0.05 were considered to be statistically significant.

Method	Study I	Study II	Study III	Study IV
Dichotomous variables				
Fisher’s exact test	X			
Pearson’s Chi-squared test (X^2)		X	X	
Continuous variables				
Mann–Whitney <i>U</i> test	X		X	
Wilcoxon’s signed–rank test		X		
Multivariate analysis				
Logistic regression			X	
Logistic regression including PSA	X	X		
Descriptive statistics				X
Software	SAS 9.3 for Windows	R statistical software 3.2.3	R statistical software 3.3.3	

PSA; propensity score analysis

Table 3. Statistical methods

4.4.1 Study I

In Study I Fisher's exact test was used for univariate group comparison of dichotomous variables, and the Mann–Whitney *U* test for univariate group comparison of continuous variables. Logistic regression was used for calculation of odds ratios and for analysis of interaction. A propensity score analysis was performed as an adjustment factor in a logistic regression model for the probability of receiving CPR before arrival of EMS. Utstein variables included were age, sex, cause of arrest (cardiac etiology or not), place of arrest (home or outside home), initial cardiac rhythm on first ECG (VF/VT or not), year of cardiac arrest (6–years intervals 1990–2011), time from collapse to call for EMS (minutes), time from collapse to arrival of EMS (minutes), and time from collapse to defibrillation of patients in VF/VT (minutes). The propensity score was used as an adjustment factor in a multiple logistic regression model. Multiple imputation for missing data in baseline variables described above was performed using the Markov chain Monte Carlo method. Two-sided tests were used and a p-value <0.05 was considered significant for the primary objective, and <0.01 for all other analyses.

4.4.2 Study II

To reduce the risk of confounding in Study II, propensity score analysis (PSA) was used to compare outcomes in the intervention group and the control group. PSA is a method used in observational studies to mimic a randomization by comparing outcomes between individuals in the intervention group vs. the control group and thereby estimate causal effects.¹⁰⁹ In Study II the calculated propensity score is the probability of receiving treatment by FRs.

Nearest neighbor matching without replacement and pre-specified caliper with were performed to compare a suitable treated case with a control case. Utstein variables used in the analysis were ByCPR (yes or no), sex, age, cardiac cause (yes or no), witnessed arrest (yes or no), place (at home or outside home), EMS response time in categories, cardiac arrest identified by dispatcher at the EMCC, year of arrest and time of day (day or night). Odds ratios and 95% confidence intervals were calculated by means of conditional logistic regression. P-values of $p < 0.05$ were considered statistically significant.

Pearson's Chi-squared test was used for comparison of dichotomous variables, and Wilcoxon's signed-rank test for comparison of continuous variables. To test for unobserved confounding, Rosenbaum bound were calculated. The Kaplan–Meier estimator for testing 11–months differences in survival between groups was used.

4.4.3 Study III

Four subgroups were analyzed; whether estimated time from emergency call to arrival of EMS/FRs was <8 min or >8 min and if ByCPR was initiated or not. Pearson's Chi-squared test was used for comparison of dichotomous variables, and the Mann-Whitney *U* test for comparison of continuous variables. Logistic regression analyses were performed to test the associations between response time, ByCPR and survival to hospital admission and to 30-days in the <8 min and >8 min groups. Utstein variables adjusted for in the two regression analyses were age, sex, place (home or outside home), cardiac cause (yes or no), EMS response time in minutes, and cardiac arrest identified by dispatcher at the EMCC. Values of $p < 0.05$ were considered statistically significant.

4.4.4 Study IV

The interviews in Study IV were analyzed by using inductive qualitative content analysis which is a method of systematic reading and analysis of texts, images, or other meaningful matter.¹¹⁰ Inductive analysis means that data is interpreted without preconceived categories or a theoretical framework that has to be proven. The study was problem-driven by the need for a deeper understanding of the FRs experiences when participating in OHCA alarms with EMS. Criterion-based case selection was used as sampling strategy, which means that all cases which met the inclusion criteria were studied.¹¹¹ As units of analysis, critical incidents (CIs) were chosen.¹⁰³ A CI is a well-defined situation with a clear beginning and end, described by the participants or observed by investigators. The specific situation studied was self-perceived experience of a cardiac arrest situation retold by the participants.

After rereading the transcribed interviews repeatedly, 60 CIs were identified and thereafter condensed to meaning-units in order to reduce the text and detect patterns. The meaning-units were interpreted and merged into sub-categories and categories, and finally three time-sequences emerged, describing the cardiac arrest situation from call out to post-mission. In every step of the analysis, scrutiny of the original text, meaning-units, and categories was carried out by the authors to ensure rigor and consistency of interpretation. Descriptive statistics were used for calculating baseline data such as age, occupational experience in years and the proportion of variables such as experiences of performing chest compression, ventilation and defibrillation.

5 RESULTS

5.1 STUDY I - EARLY BYSTANDER CPR

61,781 OHCAs were treated by EMS and included in the SRCR, of whom 30,381 were bystander-witnessed. Of these, CPR was performed before arrival of EMS in 15,512 cases (51.1%) and no CPR was provided in 14,869 (48.9%) cases.

5.1.1 Main results

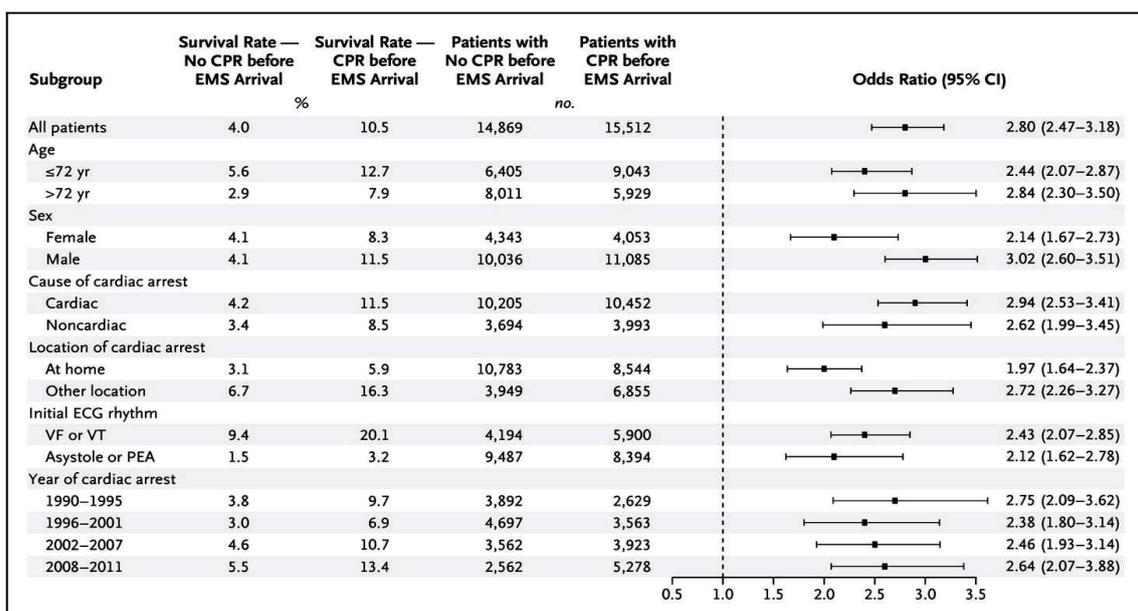
5.1.1.1 Baseline characteristics

The “no-CPR group” was older than the ByCPR group, had a higher proportion of women, collapse occurred more often at home, and they had a lower proportion of shockable rhythm on first ECG. The variable cardiac cause of arrest did not differ between groups. Time from collapse to arrival of EMS was shorter in the no-CPR group (median 6 minutes) vs. 8 minutes in the By CPR group ($p<0.001$). Median time from collapse to defibrillation by EMS was 11 (6–21) minutes in the no-CPR group vs. 13 (7–24) minutes in the ByCPR group ($p<0.001$).

5.1.1.2 Outcomes

Survival to 30-days was 10.5% in the ByCPR group vs. 4.0% if no ByCPR was performed ($p<0.001$). In a propensity score analysis including the Utstein variables¹¹² sex, age, place of arrest, cause, heart rhythm, EMS response time, time from call to arrival of EMS and year of collapse, bystander CPR before EMS arrival was associated with increased 30-day survival (OR 2.15; 95% CI 1.88–2.45). This association was found among all subgroups (Figure 5).

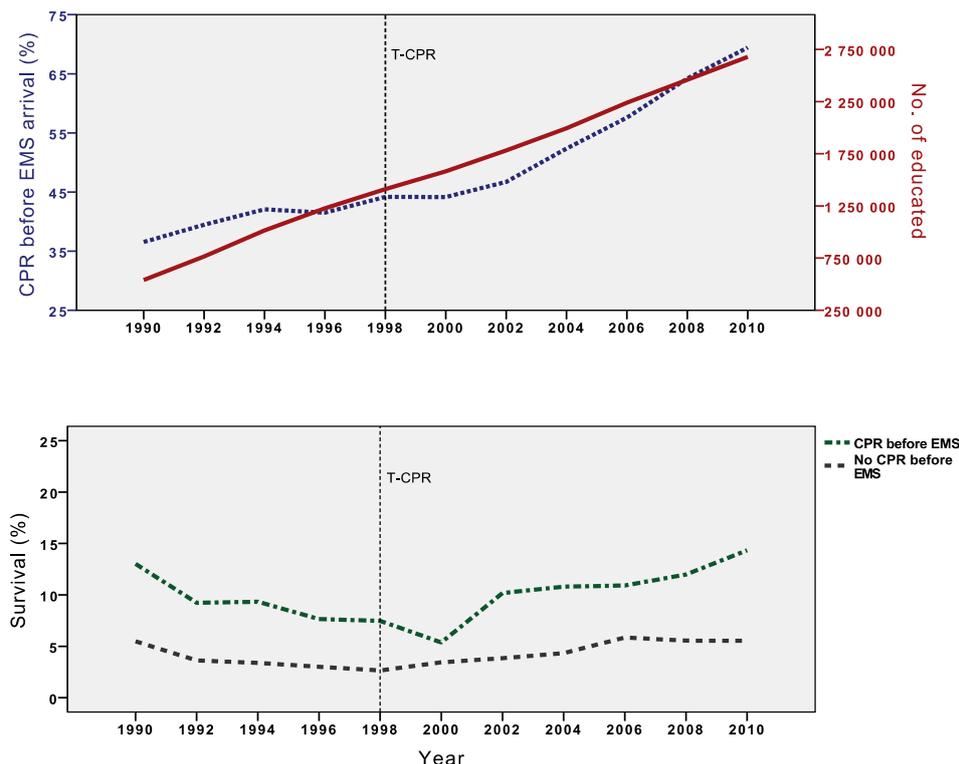
Figure 5. Subgroup analysis of survival rates



CI: confidence interval; CPR: cardiopulmonary resuscitation; ECG: electrocardiogram; EMS: emergency medical services; PEA: pulseless electrical activity; VF: ventricular fibrillation; VT: ventricular tachycardia

Changes over time regarding early CPR, 30-day survival and number of persons trained in CPR in Sweden are shown in Figure 6. The temporal trend in 30-day survival among patients receiving ByCPR before EMS arrival (green dotted line), follows the number of bystanders educated in CPR during the same time period (red line), as well as the increase in early ByCPR (blue dotted line). For the group “no CPR before EMS arrival”, 30-day survival was relatively constant during the time period.

Figure 6. Temporal trends in early CPR, survival and educated in CPR



5.2 STUDY II—SAVING MORE LIVES IN SWEDEN

The study included a total cohort of 8698 OHCA cases recorded in the SRCR, whereof 3543 occurred in intervention counties with dual dispatch of FRs, and 5155 in control counties with EMS response only.

5.2.1 Main results

5.2.1.1 Baseline characteristics

Baseline characteristics were similar in both groups before matching except for the proportion of OHCA cases recognized by the EMCCs which was greater in the intervention group, 2701/3543 (76.2%) than in the control group, 3623/ 5155 (70.3%). Shorter response times were also noticeable among cases in the control group (Paper II, Table 1). The main results after propensity score matching are summarized in Table 4.

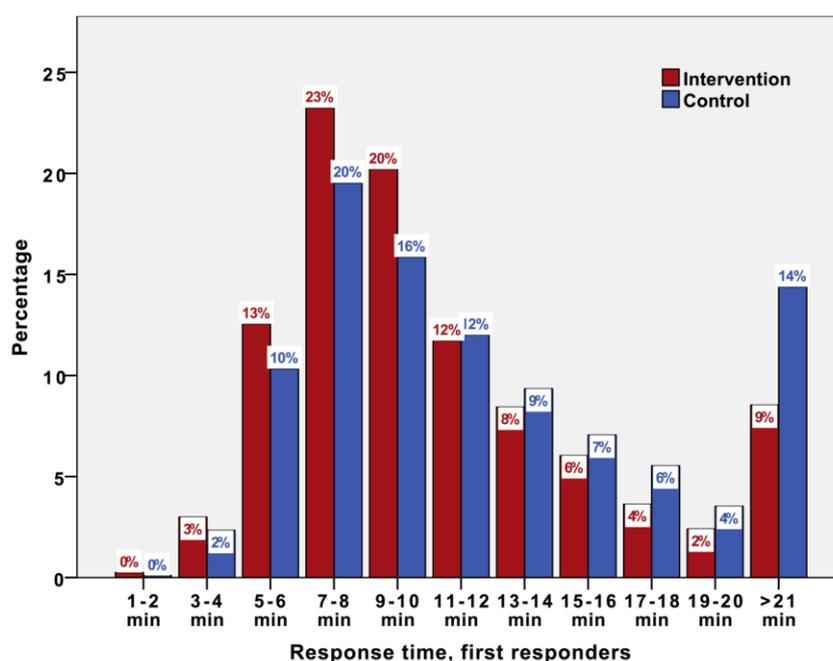
Table 4. Outcome after matching in intervention and control counties

	Intervention (n=2786) (n/%)	Control (n=2786) (n/%)	OR (95% CI) or p-value
FRs first on scene	1314 (47.2)	570 (20.5)	3.69 (3.23–4.21)
Defib by FRs	165 (5.9)	112 (4.4)	1.40 (1.09–1.80)
VT/VF	132 (22.2)	74 (12.6)	p<0.001
Admitted alive	875 (31.4)	694 (24.9)	1.40 (1.24–1.57)
VF/VT	332 (55.8)	280 (47.8)	p=0.006
30-day survival	266 (9.5)	214 (7.7)	1.27 (1.05–1.54)
VF/VT	181 (30.4)	143 (24.4)	p=0.020
Call–arrival of FRs median Q1–Q3, min	9 (7–13)	10 (8–15)	p<0.001

Defib;defibrillation, FRs;first responders, CI;confidence interval, VT;ventricular fibrillation, VT;ventricular tachycardia, OR;odds ratio, Q1–Q3;quartile 1–3

5.2.1.2 30-day survival and FR interventions

As seen in Table 4 after propensity score matching of 2786 pairs, 30-day survival was 9.5% in the intervention group vs. 7.7% in the control group (OR 1.27;95% CI, 1.05–1.54). In the intervention group the proportion of FRs first on scene was more than doubled that in the control group (47.2% vs. 20.5%). Time to treatment by FRs was one minute faster in the intervention group (p<0.001). FRs also had a faster response time from call to arrival in the first 10 minutes in the intervention group compared with the corresponding time interval in the control group (Figure 7. Response time of FRs).



5.2.1.3 Outcome in shockable cases

All dispatched incidents involved suspected CA. However, it is impossible for the dispatcher to know to in advance if every case of suspected CA really is a “true CA”. Therefore, to further analyze the value of dual dispatch of FRs, a post hoc subgroup analysis was performed concerning the cases with the highest probability of CA. These are patients in VF or VT. Such cases are covered by two major dispatch codes for suspected OHCA in the Swedish Medical Index: 1) unconscious adult, unresponsive and not breathing normally, and 2) unconscious adult with ongoing CPR. These two codes are thought to be the most representative of “true CA”.

The results in this subgroup can be seen in Table 5, showing an increased 30-day survival among patients with shockable rhythms, 109/346 (31.5%), compared with the matched cohort, 266/2786 (9.5%). Using the two same codes, the proportion of cases defibrillated by FRs was found to be significantly higher in the intervention group.

Table 5. Outcome VF/VT cases

	Intervention (n=346) (n/%)	Control (n=329) (n/%)	P-value
FRs first on scene	162 (46.8)	62 (18.8)	<0.001
Defib by FRs	85 (24.6)	49 (14.9)	0.002
Admitted alive	208 (60.1)	152 (46.2)	<0.001
30-day survival	109 (31.5)	76 (23.1)	0.018
Call-arrival of FRs median Q1-Q3, min	8.50 (7.00-11.25)	9.00 (7.00-13.00)	0.009

Defib;defibrillation, FRs;first responders, Q1-Q3;quartile 1-3

5.3 STUDY III - BYSTANDER CPR AND TIME TO TREATMENT BY EMS OR FIRST RESPONDERS

This study is based on the same cohort as in Study II, including 12,166 OHCA January 1st 2012–December 31st 2014 recorded in the SRCR and where EMS had started treatment. Of these, 7200 cases 59.2% were bystander-witnessed. The variable “response time” was missing in 24 cases, wherefore 7,176 cases remained and were analyzed regarding time to treatment by EMS or FRs, whether or not ByCPR was provided before their arrival, and survival to 30-days.

5.3.1 Main results

5.3.1.1 Baseline characteristics

The OHCA patients were divided into two groups depending on time to treatment (<8 minutes or >8 minutes). The first group consisted of 2016/7176 (28%) cases, and the second of 5160/7176 (72%) cases.

A higher proportion of patients in the <8 minutes group experienced cardiac arrest outside home, (37.6% vs. 29.3% in the >8 minutes group). VF/VT as first detectable rhythm on the ECG was found in 37.8% of cases, compared with 27.0% in the >8 minutes group. A higher proportion of patients in the <8 minutes group were indexed by dispatchers at EMCCs as cardiac arrest, 71.1% vs. 66.8%. FRs arrived at a median of six minutes (5–7) in the <8 minutes group, vs. 13 minutes (10–18) in the >8 minutes group. The proportions of women (32.2% vs. 29.5%) and of ByCPR (62.6% vs. 59.7%) were somewhat higher in the >8 minutes group. Medical etiology did not differ between groups.

5.3.1.2 Survival to 30-days

Outcome data on patient survival to hospital admission and to 30-days depending on response time of EMS/FRs and if ByCPR was provided or not before their arrival, is presented in Table 6.

Table 6. Proportion of patients admitted alive at hospital and those alive at 30 days in relation to response time and CPR performed prior to EMS/FR.

	≤ 5 min	5-8 min	9-12 min	13-17 min	>18 min	p-value
n (%)	325	2225	1851	1227	1158	
ALL PATIENTS						
Admitted alive	158 (48.9)	932 (42.2)	694 (37.9)	363 (30.0)	314 (27.4)	<0.001
CPR prior to EMS/FR	90 (50.8)	620 (46.8)	459 (40.9)	247 (32.7)	207 (28.0)	<0.001
No CPR	67 (46.2)	304 (34.9)	232 (33.0)	114 (25.6)	100 (25.3)	<0.001
Alive at 30 days	78 (24.4)	383 (17.5)	208 (11.5)	98 (8.2)	89 (7.8)	<0.001
CPR prior to EMS/FR	56 (32.0)	304 (23.2)	166 (15.0)	76 (10.2)	60 (8.2)	<0.001
No CPR	21 (14.6)	76 (8.8)	42 (6.1)	22 (5.0)	28 (7.1)	0.001
PATIENTS WITH VF AS FIRST RHYTHM						
	123	774	514	302	246	
Admitted alive	80 (65.6)	457 (59.4)	299 (58.9)	139 (47.0)	104 (43.5)	<0.001
CPR prior to EMS/FR	47 (68.1)	355 (64.9)	237 (60.8)	114 (49.8)	81 (44.3)	<0.001
No CPR	32 (61.5)	100 (45.2)	61 (52.1)	24 (36.4)	21 (38.9)	0.035
Alive at 30 days	59 (49.2)	280 (37.0)	138 (27.9)	69 (23.9)	50 (21.0)	<0.001
CPR prior to EMS/FR	43 (63.2)	232 (43.4)	116 (30.5)	57 (25.7)	37 (20.3)	<0.001
No CPR	15 (29.4)	47 (21.4)	22 (19.3)	12 (18.2)	12 (22.2)	0.614

CPR: cardiopulmonary resuscitation; EMS: emergency medical services; FR: first responders, VF: ventricular fibrillation

5.4 STUDY IV–EXPERIENCES OF SAVING LIVES IN CASES OF OHCA

The study included ten police officers and twelve firefighters in the County of Stockholm participating in a dual dispatch OHCA programme interviewed during the period of June 16th 2016 to December 13th 2016.

5.4.1.1 Baseline characteristics

The informants were predominantly men, 17/22 (77%), with a median age of 36 years and a median working experience of 6.5 years. All of the firefighters had performed defibrillation (attached pads and delivered a countershock) but among the police officers 4/10 (40%) had no such experience. Providing rescue breaths differed between groups, i.e. 4/10 (40%) of the police officers vs. 12/12 (100%) of the firefighters had performed ventilation in OHCA situations. All except five (23%) had undergone CPR training within previous year. The proportion of FRs with additional healthcare education besides professional training was 10/22 (45%).

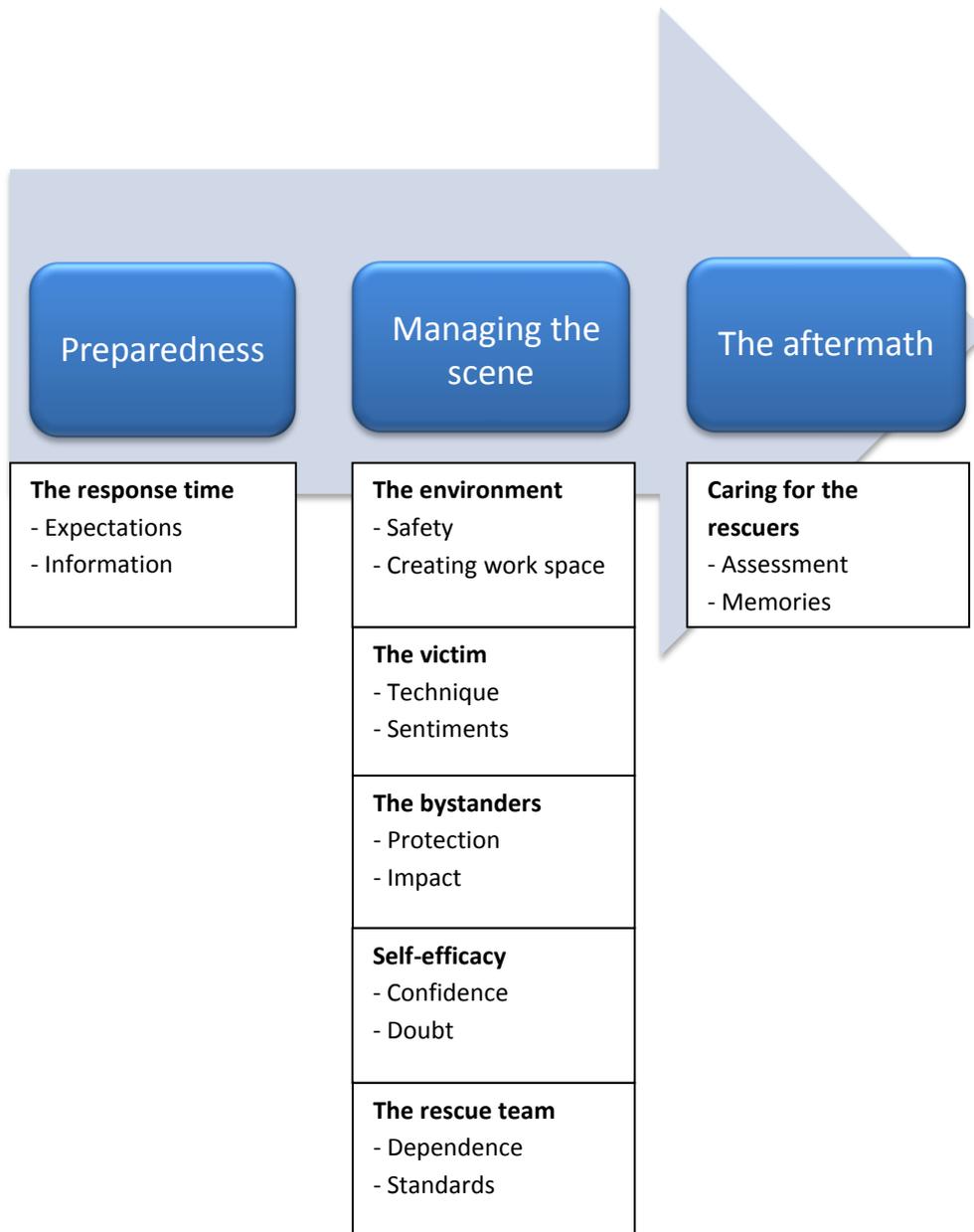
5.4.1.2 Critical Incidents

Initially 85 Critical Incidents (CIs) were identified, and after rereading each interview repeatedly, 60 of these were judged to fulfill the criteria for further analysis. On average the police officers described three CIs in the interviews, compared with two CIs among the firefighters.

5.4.2 Main findings

The main findings are summarized in Figure 8.

Figure 8. Time sequences, Categories and Sub-categories



Three consecutive time sequences could be detected in the OHCA situations narrated by the FRs. 1) *Preparedness*, describing the time from call out to arrival at the scene, 2) *Managing the scene*, was the time from arrival to departing from the location, and 3) *The aftermath*, defined as that period when no more actions were taken by FRs concerning the victim or the bystanders, to as long as memories from the occasion were preserved.

5.4.2.1 *Preparedness*

The main issue described by FRs in this time sequence was lack of information from the EMCC about the victim, the address or the entry code to the building. This caused stress and frustration amongst the FRs, and also erroneous perceptions about the victim.

5.4.2.2 *Managing the scene*

This was the most complex time sequence described. FRs had to handle the environment, the victim, bystanders if present, and self-perception about their own capacity, as well as function as a member of the rescue team. More training in CPR and especially in airway management was requested by the FRs. Education in psychological reactions amongst bystanders after an OHCA was also requested.

5.4.2.3 *The aftermath*

First responders reported the importance of taking care of the rescuers afterwards by providing assessment about the case and team performance. This action was positive and also necessary to avoid imprinted memories and occupational stress. This was reported to be particularly important in difficult OHCA cases.

6 DISCUSSION

OHCA is the greatest cause of early death among non-communicable diseases worldwide.⁵⁻⁷ It is well known that early ByCPR started immediately after collapse, and rapid defibrillation are the two main keys to change the discouraging trend of poor survival within the OHCA population.^{64, 81} Three studies included in this thesis demonstrate different aspects of the problem and possible ways to contribute to important evidence-based interventions regarding survival in OHCA. In the fourth study interviews of first responders engaging in saving lives in cases of OHCA have highlighted aspects of better understanding the rescuers' views.

6.1 HOW CAN WE INCREASE RATES OF BYSTANDER CPR IN THE COMMUNITY?

One option could be to further optimize dispatcher assisted T-CPR. In a meta-analysis of 252 papers on determinants of ByCPR, Vaillancourt et al. classified recommendations where the highest level of evidence where T-CPR.¹¹³ T-CPR was not associated with a higher rate of 30-day survival in OHCA compared with early ByCPR in a cohort of 4349 cases (10.9% vs. 15.4%, $p < 0.001$) in Study I. One reason might be that valuable time is lost when

instructing non-skilled bystanders how to perform T-CPR, especially in residential areas, where the bystanders may be older and more often alone, compared with public locations.¹¹⁴ However, T-CPR has been proven to increase survival in cases of OHCA in a meta-analysis and several other studies.^{49, 54, 115}

2. Educate more people in CPR. In Sweden approximately 3 million people have over the years undergone some level of CPR training on one or more occasions. This is reflected in the high level of ByCPR at a national level. Mass training in CPR in society is often advocated as a universal tool for improving the ByCPR rate, and survival. For example, CPR could be mandatory in elementary schools. However, such intervention has been associated a low grade of evidence and has not proven to be effective.^{113, 116}

3. Recruitment of lay volunteers trained in CPR, and by using mobile phone technology has on the other hand demonstrated promising results as a means to increase the ByCPR rate.¹⁰⁷

4. Simplified and shortened CPR courses.⁷³

6.2 IS THE TYPE OF BYSTANDER PERFORMING CPR IMPORTANT FOR SURVIVAL?

No differentiation was made between rescuers in Study I; they were all classified as “bystanders” irrespective of level of acquired CPR training or previous professional health-care education. The competence of bystanders providing CPR before EMS arrival is reported in three categories to the SRCR by the attending ambulance crew: 1) laymen trained in CPR, 2) laymen not trained in CPR, and 3) medically educated people not participating in an emergency response system. In a recent SRCR study, Nord et al. demonstrated improved 30-day survival in cases of OHCA if the bystanders providing CPR were medically educated, compared to lay bystanders (17.2% vs. 14.7%, $p=0.02$).¹¹⁷ The quality of CPR given by medically educated bystanders could explain the better outcome. On this we can only speculate.

High-quality CPR is more frequently observed when there are multiple rescuers at the scene of the arrest.¹¹⁸ This could be one of several explanations for improved 30-day survival in the interventions counties in Study II, where there were more FRs in place of the arrest.

6.3 DOES THE TYPE OF CPR MATTER FOR SURVIVAL?

The importance of ventilation or rescue breaths has over the years shifted to prioritize compressions. Since the First International Conference on Guidelines for CPR and Emergency Cardiac Care in 2000, instructions on how to perform BLS have developed from

two rescue breaths followed by 15 chest compressions, to the present BLS algorithm for adults, which is 30 compressions and two rescue breaths.^{1, 119}

In a summary statement from the International Liaison Committee on Resuscitation (ILCOR) 2017, dispatch-assisted compression-only CPR is strongly recommended when suspecting adult cases of OHCA. However the evidence is of low quality according to GRADE Quality Assessment Criteria.¹²⁰ Earlier randomized studies concerning examination of whether or not the bystander continuous compression-only technique is preferable to CPR with both compression and rescue breaths, showed no difference in 30-day survival between the groups.^{53, 54}

Lay ByCPR with the compression-only technique has proven to increase the rate of survival to discharge compared with conventional CPR amongst a cohort of 4415 adult cases of OHCA in a US study (13.3% vs. 7.8%).¹²¹ Results from a recently published Cochrane review including four studies indicated that more people survived to hospital discharge if they had received ByCPR with chest compressions only, compared with standard CPR performed with a 15:2 ratio (14% vs. 11.6%).¹²² The optimal ratio of compressions and ventilation is still under scrutiny and requires further research.

The type of ByCPR administered was not analyzed in Study I. In no educational Swedish program is chest compression only recommended. However, data from 2016 in Sweden demonstrates that compression-only CPR was performed more frequently before arrival of EMS or FRs, than standard CPR with a 30:2 technique (57.4% vs. 41.1%).⁹ This phenomenon is probably dependent on an increase in T-CPR. New treatment recommendations from ILCOR for all cardiac-arrest patients are still both rescue breaths and chest compressions if the bystander is trained and willing. The evidence for this recommendation, however, is weak and of very low quality.¹²⁰

6.4 HOW RELIABLE IS REGISTER DATA?

The data in Studies I–III include OHCA reports from EMS since 1990 and at that time the SRCR did not cover all ambulance organizations in Sweden, which makes interpretation of the data more uncertain and not representative of the whole OHCA population at the time. Since 2009 all ambulance organizations have reported to the register. However, this is not the same as all CA are reported within the register. Approximately 25% of all OHCA may not be reported by EMS. Since 2011 more intense validation of outcome data in the SRCR is performed by retrospective audits which can improve this “patient data missing” situation. This validation procedure is described above (Section 4.1.1).

6.4.1.1 *Can we rely on the time estimates?*

Estimated time measurements reported in Study I concerned the delay from collapse to call for EMS. In this aspect about 20.0% of all patients had missing data as in regards this variable. Other important missing data concern the delay from collapse to start of ByCPR (21.2% missing) and delay from collapse to defibrillation (5.3% missing). Multiple imputation using the Markov chain Monte Carlo method was therefore used to handle missing data on primary outcome.

6.5 DUAL DISPATCH AND OUTCOME: ARE WE SAVING LIVES?

An overview over 25 dual dispatch studies 1988 to 2017 is presented in Appendix Table 1A conducted in the US (12), Sweden (4), Canada (2), Italy (1), The Netherlands (1), Australia (1), New Zealand (1), Northern Ireland (1), Denmark (1) and Switzerland (1). The preponderance of studies involved firefighters and EMS (12), followed by police officers/EMS (5), police officers/firefighters/EMS (4), and combined groups of fire fighters/lay rescuers/EMS (1), police officers/lay rescuers/EMS (2), and firefighters/police officers/other BLS activated-crews/bystanders/EMS (1).

In a majority of studies comparison were made with historical controls. In Study II we used controls from the same time period as the intervention; thus confounding could be avoided as regards altered guideline recommendations concerning CPR. In-hospital treatment interventions that may affect survival were not investigated in Study II. This interaction was examined earlier in a study from Stockholm County showing improved survival to both 30-days and three years in the dual-dispatch group compared with EMS only, despite no major differences in hospital treatment between groups.¹²³

The sample sizes included in the above-mentioned studies were usually small, varying from 80 OHCAs, to the largest, 8698 in our Study II. Only five of the reported studies included >1000 cardiac arrests. The majority of all studies encompassed adult OHCAs independent of cardiac rhythm. Four of them had specified VT/VF as an inclusion criterion. Cases of OHCA cases with shockable rhythm have the best chances of survival, and in a sub-study of VT/VF cases, we confirmed this finding described in earlier dual-dispatch studies (Appendix, Table 1A).^{87, 88, 124}

Outcome results regarding survival varied greatly between studies and ought to be interpreted as being caused by differences in EMS and dispatch systems between settings, and also type of study design used. Moderately but significantly improved 30-day survival in cases of

OHCA was seen in Study II and also in other FR studies with similar interventions.¹²⁵⁻¹²⁷ However other studies have showed no beneficial impact on survival.^{124, 128, 129}

6.6 POLICE OFFICERS AS A THIRD TIER IN DUAL DISPATCH, IS 1+1+1 REALLY 3?

There are previous conflicting results in regard to involving police officers in the chain of survival. In one study police officers as a third tier with EMS and fire-fighters did not improve survival in cases of OHCA.¹²⁶ However, in a legendary publication from Dade County in Florida, Myerburg et al. found that police response times were faster compared with historical EMS data, and survival in VT/VF cases increased when defibrillated by the police. No benefits were seen in cases with nonshockable rhythms.⁸⁸ This has been the raw model of our engagement in police officers attendance in the Swedish dual dispatch program.

The role of the police as an additive factor with EMS and firefighters for early CPR and defibrillation in cases of OHCA has yet to be more thoroughly investigated in Sweden and internationally. In Study II only two participating counties had enrolled police officers in this dual dispatch programme and the number of reported police assignments included in Study II was relatively small, approximately 500 cases. This police involvement has therefore to be considered as to be a pilot study.

6.6.1.1 What is the advantage of police involvement?

Police officers are often moving around in the neighborhood in their patrol vehicles, which should imply shorter response times to the victim, whereas firefighters are usually at the fire station, or at their regular work place if part-time employed. Yet the firefighters in our report were faster in OHCA alarms, and one reason for this is the current Swedish delayed police dispatch system. In the SRCR EMS were first on the scene in 70% of cases of OHCA, followed by 21% for the firefighters and 3.5% for the police.⁹

6.7 STUDY DESIGN—COULD WE HAVE PERFORMED A RANDOMIZED TRIAL INSTEAD?

None of the 25 studies described above were true randomized controlled trials. Some were prospective or retrospective observational studies including a “before and-after design”, with EMS time measurements used as comparison. One study involved open cluster randomization with periodic cross over, showing only a modest benefit of defibrillation by first responders.⁹⁰ The difficulty in randomizing FRs to either dual dispatch with EMS or not, is not so much a logistical problem as (for us) an ethical issue. The reason for this stems from results of earlier dual dispatch studies in Stockholm County demonstrating increased survival

in cases of OHCA.^{2, 30, 123} Therefore, ethical reasons made it difficult to obtain ethics permission for a randomized controlled trial in the planning of Study II.

The disadvantages of cohort studies mainly concerns causality, selection bias and confounding. However, a well-designed intervention study can have a higher level of evidence than an imperfectly conducted randomized controlled trial with a large proportion of loss to follow-up, or poor randomization and blinding procedures.¹³⁰ Another option is to perform propensity score matching as we did in Study II as a possible way to reduce confounding.

6.8 IS A TIME LIMIT OF EIGHT MINUTES TO DEFIBRILLATION REALISTIC IN OHCA?

Time to treatment is crucial in cases of OHCA. In Study III we found that if the time to initiate treatment performed by EMS/FRs was <5 minutes and if early ByCPR had been started, 30-day survival was 32% for all patients. In the most advantaged group, the VT/VF group with ByCPR provided, 30-day survival was even higher, 49.2%. This is in line with what the Seattle group found 30 years ago. This “eight-minute time span” was originally described by Eisenberg et al. They demonstrated that if ByCPR started within four minutes of collapse and time to more definitive care (such as defibrillation) was <8 minutes, 43% of all patients could be discharged from hospital.¹³¹ These golden minutes have thereafter found their way into several ambulance response standards, with different goals set accordingly. Another example is from the United Kingdom where the goal is to have 75% of ambulances reaching OHCA within eight minutes.¹³²

With a similar study design as ours, Park et al. studied the importance of the time from collapse to start of ByCPR and they used four time intervals, all depending on EMS arrival: <4 min, 4 min–8min, 8–15 min, and 15–< 30 min. In the fastest group 15% of the patients survived to hospital discharge, compared with 4.8% in the slowest group.¹³³ Furthermore, long EMS response times are likely to reduce the incidence of VT/VF, and impair outcome. For every minute of prolonged EMS time, the odds of patients having a shockable heart rhythm declines by 8%.¹³⁴ This was also shown in Study III, where the proportion of shockable rhythm declined in every demonstrated time interval, from 37.8% for ≤5 minutes, to 21.2% in >18 minutes.

One can only speculate if eight minutes or less for time to definitive care is achievable in large urban areas with constant traffic jams hindering both EMS and FRs. In rural areas distance and scarce EMS resources are other obstacles. A report from the Swedish Heart–

Lung Foundation based on data from EMCCs, revealed that response times for EMS increased in 15 of 21 counties in Sweden in 2012–2016, now exceeding ten minutes in urban city areas and 16 minutes in more rural regions such as Jämtland and Gotland.¹³⁵ The presence of organizations other than EMS taking part in OHCA dispatch seems necessary to reduce response times and improve outcome for this patient group. To follow up, register and benchmark response times in life-threatening emergency care amongst EMS organizations is the only path for improvement.

6.9 WHAT CAN WE LEARN FROM THE RESCUERS?

In qualitative studies more profound and deeper thoughts, feelings and experiences about a phenomenon can be revealed than through for example questionnaire surveys which can be too superficial. Therefore qualitative and quantitative studies can complement each other and exhibit different angle on the research project. Interviews of FRs participating in dual dispatch have provided information about how they perceived the cardiac arrest situation, and it was described as complex and sometimes difficult to control, depending on the environment, the victim and the bystanders.

More police officers were uncertain about their own performance in OHCA situations than the firefighters who had been engaged for longer in OHCA alarms. Insecurity in handling the victims' airways and attaching AEDs has also been reported in earlier studies amongst police officers.^{136, 137} Training in BLS and defibrillation with annual refresher courses is required to maintain psychomotor skills, to boost self-esteem and to increase performance in cases of OHCA, not just for the individual but for the whole rescue team.^{138, 139} This is important to take into account before introducing dual dispatch in any prehospital setting.

Defusing after mission with the team was appealed for, several of the FRs thought this could be a method to ease the burden after difficult missions, thus avoiding occupational stress and bad memories. An issue that causes stress and frustration amongst FRs was lack of information from the EMCC about the address or the victim.

Experiences from many years of work as in regards to dual dispatch in Stockholm County have led to recognition of the need of a “collaboration network” with participants from the “chain of survival” such as EMCCs, EMS, the police– and fire organizations and cardiac arrest researchers. It is important to discuss difficulties during OHCA alarms and further to spread this information to each participating organization. Implementing such a network is highly recommended to increase understanding between organizations.

7 CONCLUSIONS

- Early ByCPR initiated before arrival of EMS more than doubled 30-day survival in cases of OHCA. This finding was consistent among all prespecified subgroups analyzed.
- Implementation of a national dual dispatch system of EMS and first responders in cases of OHCA providing CPR and potentially defibrillation, is associated with a shortened response time, more patients admitted to hospital alive and a moderate but significant increase in 30-day survival.
- The combination of reduced response times of EMS and FRs to less than eight minutes in cases of witnessed OHCA, and early ByCPR initiated before their arrival, can substantially improve 30-day survival, especially in cases with a shockable heart rhythm.
- When introducing dual dispatch of first responders as a second tier in cases of OHCA, CPR and hands-on AED training must be repeated annually to maintain CPR skills. Education in psychological reactions amongst bystanders should also be addressed, and team assessment offered after mission is important to avoid occupational stress.

8 FUTURE PERSPECTIVES

While working on this project several questions have emerged:

How can more lay people in society be inspired to take a CPR course, not only once but repeatedly to maintain retention in psychomotor skills?

Implementation of dual dispatch of EMS and first responders in the whole of Sweden in a three-year perspective—is it feasible?

Are there other organizations and civil groups we can incorporate and dispatch to save lives in cases of OHCA?

How can we further shorten the time to dispatch of EMS and first responders? And how can we improve accuracy in identifying OHCA at EMCCs? Can artificial intelligence (AI) be a work tool for improvement?

Is it possible to transfer the OHCA alarm from EMCCs digitally or by using SMS system directly to police officers on duty or to the police dispatch center and into the closest police cell phones without violating the chain of command thus improving response times?

Can new technical solutions such as drones provide AEDs to bystanders for early defibrillation especially in rural areas?

Data-driven performance-focused debriefing is recommended by the European Resuscitation Council to improve team work in cases of OHCA. Is it possible to create a mobile phone- and desktop-adapted programme for FRs and EMS to use after mission?

9 SAMMANFATTNING (SUMMARY IN SWEDISH)

Årligen rapporteras ca 5300 fall av oväntat hjärtstopp utanför sjukhus i Sverige, och av dessa avlider 90%. Den viktigaste orsaken till den höga dödligheten är det har förflutit för lång tid innan hjärtlungräddning (HLR) startas. För varje minut som går utan behandling med HLR och defibrillering med en hjärtstartare minskar chanserna till överlevnad med 7–10% per minut. Studier har visat att om defibrillering sker inom tre minuter från kollaps kan så många som 70% räddas. Ambulansens responstid i Sverige har ökat de senaste 10 åren vilket gör att de alltför ofta kommer för sent. Det är därför viktigt att nya metoder utvärderas för att snabbare nå den drabbade.

Syftet med avhandlingsprojektet har varit att fokusera på betydelsen av att tidigarelägga vården före ambulansens ankomst och belysa om tidig HLR och defibrillering kan öka överlevnaden vid hjärtstopp utanför sjukhus genom samutlarmning av ambulans, räddningstjänst och/eller polis på nationell nivå.

Studie I. I en första registerstudie undersöktes vilken betydelse tidig HLR före ambulansens ankomst har för överlevnad vid hjärtstopp utanför sjukhus. Resultatet visade att överlevnaden till 30-dagar var 10.5% i gruppen som erhållit HLR före ambulansens ankomst jämfört med 4.0% i gruppen som ej erhållit HLR. Slutsatsen var att överlevnaden mer än fördubblades om tidig HLR gavs av lekmän i väntan på ambulans.

Studie II. I en nationell interventionsstudie genomförd 2012–2014 larmades räddningstjänst och/eller polis ut samtidigt som ambulans vid misstänkta hjärtstopp utanför sjukhus i nio svenska län. Gruppen jämfördes med fall från 12 andra län där ingen samutlarmning skett. Totalt inkluderades 8698 hjärtstoppfall. Resultaten visade att överlevnaden till 30-dagar var 7.7% i län utan samutlarmning jämfört med 9.5% i län med samutlarmning. Vidare anlände räddningstjänst eller polis en minut snabbare till hjärtstoppet i län med samutlarmning och inlagda levande på sjukhus ökade från 26.2% till 32.4%. Slutsatsen blev att samutlarmning är en åtgärd som kan bidra till att öka överlevnaden vid hjärtstopp utanför sjukhus.

Studie III. I delstudie 3 belystes betydelsen av ambulansens responstid. Totalt inkluderades 7200 bevitnade hjärtstopp utanför sjukhus. Resultaten visade att högst överlevnad till 30-dagar sågs i gruppen med HLR påbörjad av lekman och ankomsttid för ambulans eller räddningstjänst/polis inom fem minuter (32%), i jämförelse med om ingen påbörjat HLR och med samma ankomsttid (14%). Slutsatsen blev att HLR påbörjad av lekman och tid till påbörjad behandling av ambulans eller räddningstjänst/polis inom åtta minuter väsentligt förbättrade överlevnaden.

Studie IV. I delarbete 4 belystes med en kvalitativ ansats upplevelser av att larmas ut vid misstänkta hjärtstopp och att delta i livräddning i ett samutlarmningsprojekt, genom att 22 räddningstjänstpersonal och poliser i Stockholms län intervjuades. De viktigaste fynden var 1) poliserna och räddningstjänstpersonalen upplevde frustration när de hade fått för lite information från larmcentralen om hjärtstoppsfallet, 2) mer HLR träning behövdes, speciellt när det gäller luftvägshantering, liksom utbildning i hur efterlevandes reaktioner skulle bemötas, 3) falldiskussion för personalen initierad av chef efter uppdragets slut efterlystes, speciellt gällde detta mer komplicerade hjärtstoppsfall.

Slutsatser. Prehospitala åtgärder som väsentligt kan öka överlevnaden vid hjärtstopp utanför sjukhus med en synergistisk effekt är tidig HLR av lekmän och samtidig utlarmning av ambulans, räddningstjänst och/eller polis för behandling med HLR och eventuell defibrillering. Åtgärder för att väsentligen minska ankomsttider till hjärtstoppsspatienten bör vidtas och tidsatta mål eftersträvas som kvalitetsindikator inom ambulanssjukvården. Vid implementering av samutlarmning måste speciellt fokus läggas på återkommande utbildning för insatspersonalen och falldiskussioner efter uppdrag.

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12 APPENDIX

12.1 TABLE 1A. OVERVIEW OF FIRST RESPONDER STUDIES 1988–2016

Appendix Table 1A. Overview of FR studies

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criterias	First responders	Results	Comments
Weaver et al. (1988)	Seattle, US	Prospective cohort	25 months from May 1984	1287	Survival to hospital discharge	OHCA cases in VF	Firefighters	Higher survival (30%) if FRs used an AED, than if BLS only was provided by FRs before EMS arrival (17%).	Comparison with EMS. Findings support the use of AED by FRs.
Kellerman et al. (1993)	Memphis, US	Nonrandomized, controlled clinical trial, periodic cross over	March 3, 1989 – June 8 1992	879	Survival to admission, Survival to discharge, ROSC in field, Neurological status at discharge	Adult OHCA with cardiac cause	Firefighters	No major survival differences between groups (Defib by FRs vs. defib. by EMS). Higher survival in VF/VT group.	Comparison with EMS. The benefit of dual dispatch in an urban setting was small regarding survival.
Schuster et al. (1993)	Hamilton-Wentworth, Canada	Retrospective cohort	May 1, 1990 – April 30, 1991	297	Survival, Mean defibrillation time	Adult OHCA with cardiac cause	Firefighters	Greater survival in VF cases, By-witnessed, and ROSC on ED arrival. FRs shocked 3.5 min faster than EMS.	Comparison with EMS. Other EMS systems should consider FR defib.
Callahan et al. (1996)	San Francisco, US	Prospective observational study	July 15, 1992 – May 27, 1993	544	Time intervals between FR and EMS arrival, treatment interventions and outcome	Adult OHCA cases with cardiac cause	Firefighters	3.2 min arrival gap between FRs and EMS. No time intervals to treatment were related to outcome.	Comparison with EMS. ALS was related to poorer outcome. ByCPR and early defib increased survival

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criterias	First responders	Results	Comments
White et al. (1996)	Rochester, US	Retrospective observational outcome study	Nov 1990 – July 1995	84	Survival to discharge, Time from call to first shock, ROSC	OHCA in VF with cardiac cause	Police officers	Survival to discharge 41 (49%). Call to shock for all was less in the police group. ROSC 28 (33%) cases.	Comparison with EMS. Short call to shock and ROSC after defib are determinants of survival.
Ho et al. (1997)	Minneapolis, US	Retrospective, descriptive design	Jan 1, 1993- June 30, 1995	271	Survival, Neurological outcome	OHCA in VF /VT with cardiac cause, >40 kg	Firefighters	22 (20%) survived to discharge. 109 cases of VF/VT shocked by FRs. 17 had GCS 1-2 (77%), VF/VT.	Comparison with EMS. FRs using AED in an urban setting could improve outcome in VF/VT.
Mosesso et al. (1998)	Allegheny County, US	Prospective, interventional cohort study	1) Jan 1, 1990 – Jan 31, 1992 2) Feb 1, 1992 – Jan 31, 1995	Period 1) 80 in VF, Period 2) 127 in VF	Survival to discharge in VF/VT, Difference in time from call to defib	Adult non traumatic OHCA	Police officers	No difference in survival to discharge. Time to shock decreased from 12 to 9 min.	Comparison with EMS. Historical controls. Police AED use was an independent predictor of survival.
Stiell et al. (1999)	Ontario, Canada	Controlled clinical trial, before - after	1994-1999	Control 4690 Intervention 1641	Survival to hospital discharge	Adult OHCA >16 years, cardiac cause	Firefighters	Survival improved for all rhythms from 3.9% in control to 5.2% in intervention.	Comparison with EMS. Historical controls. Optimizing rapid defib. in a BLS/EMS system could improve survival.

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criteria	First responders	Results	Comments
Groh et al. (2001)	Indiana Counties, US	Observational study, before - after	Controls 1995-1996. Intervention May 1997 - Dec 1999	472 control 388 intervention	Survival to discharge for OHCA in VF/VT	Nontraumatic OHCA >18 years	Police officers	3 (15%) of VF/VT survived after police defib. vs. 16 (10%) for EMS. OHCA survival did not improve	Comparison with EMS. Historical controls. Low police response to OHCA.
Smith et al. (2001)	Melbourne, Australia	Prospective controlled trial	July 14, 1998 - 22 June 1999	268 control, 161 intervention	Time to EMS arrival, Time to defib.	OHCA cardiac cause	Firefighters	Reduced response time 1.6 min. Time to defib 1.43 min faster.	Comparison with EMS. Dual dispatch should be considered.
Capucci et al. (2002)	Piacenza, Italy	Prospective intervention study	June 6, 1999-April 30, 2001	354	Survival to discharge, Call to arrival time	OHCA	Lay volunteers Police officers	Survival to discharge rose from 3.3% for EMS vs. 10.5% for Lay/Police. Call to arrival EMS 6.2 min vs. Lay 4.8 min.	Comparison with EMS. Defib. only, no CPR provided by Lay/Police group.
Myerburg et al. (2002)	Miami, US	Observational study, before - after	Controls Sept 1997 - July 1999. Intervention Feb 1, 1999 - April 30, 2001	318 control, 420 intervention	Survival, Time from call to arrival of Police/EMS	OHCA cardiac cause	Police officers	17.2% survival in VF for FR defib. vs. 9% in EMS only. Arrival of Police/EMS 4.9 min vs. 7.6 min. EMS only.	Comparison with EMS. Historical controls. No benefits for nonshockable rhythms.
Van Alem et al. (2003)	Amsterdam, NL	Randomized open clinical trial, periodic cross over design	Jan 2000 - Jan 2002	226 control, 243 intervention	Survival to discharge, ROSC, Admission to hospital	Witnessed OHCA, cardiac cause >18 years	Police officers Firefighters	Survival 18% in intervention vs. 15% in control. ROSC 57% vs. 48%. Admission to hospital 42% vs. 33%.	Comparison with EMS. Modest benefit of defib. by FRs.

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criterias	First responders	Results	Comments
Sayre et al. (2005)	Cincinnati, US	Prospective cohort study	March 1, 1997 – Feb 28, 1999	427 control, 154 intervention	Survival to discharge	OHCA cardiac cause, >8 years	Police officers Firefighters	Survival to discharge 7.1% in intervention vs. 3.8% in control.	Comparison with EMS. Police defib as a third tier in OHCA did not improve survival to discharge.
White et al. (2005)	Rochester, US	Retrospective observational outcome study	Nov 1990, - Dec 2003	193	Survival neurologically intact, Call to shock, ROSC	Adult OHCA, cardiac cause in VF	Police officers Firefighters	80 (41%) discharged neurologically intact. Reduced call to shock time, improved ROSC rate.	Comparison with EMS. High survival in VF can be obtained by dual dispatch of FRs and EMS.
Moore et al. (2008)	Northern Ireland	Prospective intervention study, before - after	1 Jan, 2004 – 31 Dec 2004, and 2005-2006	642	Survival to discharge, Call to response time	OHCA cardiac cause	Police officers Lay volunteers	Survival 2.5% (2004) vs. 3.5% (2005-2006). Improvement in call to response.	Comparison with EMS. Historical controls. Survival did not improve.
Hollenberg et al. (2009)	Stockholm, Sweden	Prospective observational study, before - after	2004 and 1 Dec, 2005-31 Dec, 2006	657 controls 863 included	Survival to 30-days, Call to arrival of FRs, Patients in VF	Adult OHCA	Firefighters	Survival 30-days rose 5.7% to 9.7% for witnessed cases. Decreased arrival time from 7.5 to 7.1 min. VF ratio was unchanged.	Comparison with EMS. Historical controls. Dual dispatch might have improved survival.

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criterias	First responders	Results	Comments
Hoyer et al. (2009)	Aarhus, Denmark	Prospective observational study	Sept 1, 2005 – Dec 31, 2007	1076 patient contacts → 53 OHCA	Arrival of BLS before EMS, Use of AED, Successful defib.	OHCA	Firefighters	BLS responders arrived before EMS in 789 cases (73%). AED attached in 29 cases, 8 were defibrillated, 6 survived to 30-days.	Comparison with EMS. BLS response may have resulted in successful resuscitations.
Swain et al. (2011)	Wellington, NZ	Retrospective comparative study	1 July, 2007-31 Dec, 2009	339	Survival to discharge, Response time of FRs	OHCA >16 years, cardiac cause	Firefighters	37 (11%) survived to discharge. Arrival time of FRs 6.5 min. vs. 9.7 min. for EMS.	Comparison with EMS. No beneficial impact on survival was noticed.
Becker et al. (2013)	King County, US	Prospective observational study	March 1, 2010 - March 31, 2012	231	Arrival time of FRs, Provision of CPR and defib. by FRs	Non traumatic OHCA	Police officers	FRs arrived before EMS in 16%. CPR in 29/37. Shock delivered in 6/6 cases.	Comparison with EMS. Police was dispatched slower than EMS.
Saner et al. (2013)	Olten, Switzerland	Prospective observational study, before - after	1997 – 1998, and Jan 1, 2001-Dec 31, 2008	46 controls, 238 OHCA in intervention	Discharged from hospital, Response time of FRs, CPR interventions	OHCA	Firefighters Lay rescuers	18 cases discharged. FRs arrival time 6 min vs. 12 min by EMS. CPR initiated by FRs in 164 (69%) of cases.	Comparison with EMS. Historical controls. Second tier of FRs increased survival.

Author (Year)	Country	Study design	Time period	Sample size (n)	Outcomes	Inclusion criteria	First responders	Results	Comments
Nordberg et al. (2014)	Stockholm, Sweden	Prospective interventional study, before-after	2004, and 2006-2009	620 controls, 1961 in intervention	30-day survival, three-year survival, response time by FRs, inhospital treatment	Adult OHCA >18 years, cardiac cause	Firefighters	30-day survival 3.9% in control vs. 7.6% in intervention. Three-year survival 2.4% vs. 6.5%. Shortened response times.	Comparison with EMS. Historical controls. No major differences in in-hospital treatment between groups.
Malta Hansen et al. (2015)	North Carolina, US	Prospective interventional study	2010-2013	4961	Survival to discharge with CPC-1,2, Resuscitation efforts before EMS arrival by FRs, bystanders or both	OHCA, cardiac cause	Firefighters Police officers Other BLS activated crews Bystanders	Survival CPC 1-2 increased from 7.1% to 9.7%. By-CPR plus FR defib increased from 14.1% to 23.1%.	Comparison with EMS. By-CPR and defib by FRs was associated with increased survival.
Hasselqvist-Ax et al. (2017)	Sweden	Prospective cohort study	1 Jan 2012 – 31 Dec 2014	8698	Survival to 30-days, Arrival time of FRs	Adult OHCA >18years cardiac cause	Firefighters Police officers	Survival 9.5% in intervention vs. 7.7% in control. FRs arrived 1 min before EMS.	Comparison with EMS. Higher survival in VF group. Dual dispatch of FRs should be considered.

AED,automated external defibrillator, ALS,advanced life support, BLS,basic life support, By-CPR,bystander cardiopulmonary resuscitation, CPC,cerebral performance category, CPR,cardiopulmonary resuscitation, Defib,defibrillation, EMS,emergency medical services, FRs,first responders, OHCA,out-of-hospital cardiac arrest, ROSC,return of spontaneous circulation, VF,ventricular fibrillation, VT,ventricular tachycardia