Recognition of out-of-hospital cardiac arrest (OHCA) is vital for victims. During the emergency call, dispatchers’ recognition of OHCA relies on answers provided about cardiac arrest symptoms. However, OHCA might be recognised more exactly using mobile phone technology which records and analyses a victim’s cardiac rhythm (rhythm-based approach). This thesis describes the impact of OHCA recognition on survival rate and considers the option of using mobile technology to help recognise OHCA.
RECOGNITION OF OUT-OF-HOSPITAL CARDIAC ARREST
Sakari Syväoja

RECOGNITION OF OUT-OF-HOSPITAL CARDIAC ARREST

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ABSTRACT

Cardiovascular diseases (CVDs) are the primary cause of human death in the world. The most shocking manifestation of CVD is sudden cardiac arrest (SCA). Approximately four to five million sudden in-hospital or out-of-hospital cardiac arrests (OHCAs) occur worldwide annually. In Finland, there are approximately 4,300 cases of OHCAs each year.

Survival of OHCAs depends on the sequence of interventions in the “chain of survival”. One important factor is the time from collapse to onset of cardiopulmonary resuscitation (CPR) efforts. Each passing minute of untreated cardiac arrest reduces the likelihood of survival. Without recognition of OHCAs, there are seldom CPR efforts before the arrival of the emergency medical service (EMS) unit. This time delay can be fatal for the OCA patient.

To recognize cardiac arrest over the phone during the emergency call, emergency medical dispatchers ask a number of standardised questions including information about the victim’s consciousness, absence of breathing or presence of abnormal breathing, thus the recognition of OHCAs leans on questions concerning cardiac arrest (CA) symptoms. With this routine practice dispatchers recognize approximately 50–80% of OHCAs. However, OHCAs might be recognized more promptly using a “rhythm-based” approach, whereby a victim’s cardiac rhythm is recorded with mobile phone technology that analyzes and transmits recordings to Emergency Medical Communication Centres (EMCCs) for further interpretation.

This study aimed to describe the impact of dispatcher recognition of OHCAs on the survival rates of patients and on the principal elements of the chain of survival. In addition, the fundamental question of whether the quality of readings recorded within a mobile phone-sized area would be eligible for the rhythm-based approach of OHCAs was examined, and the possibility of applying mobile phone technology to record OHCAs’ electrocardiograms (ECGs) to facilitate the recognition process was considered.

To define the impact of OCA recognition in the EMCC on the survival rates of patients and on the principal elements of the chain of survival altogether 2054 bystander-witnessed OHCAs events of cardiac origin from the Helsinki University Hospital’s registry of OHCAs patients between 1997 and 2013 were analysed. To evaluate the option of mobile phone technology being settled in the OCA recognition process, the analysis of a normal ECG rhythm and one of a CA rhythms, ventricular fibrillation (VF)—recorded under an area of a mobile phone—were performed by an automated external defibrillator (AED) software and two cardiologists. ECGs were recorded with small pads in an area the size of a mobile phone on 20 healthy volunteers in four different positions over the chest during rest and during interference of muscle tension, and on 22 cardiac patients on the mid-sternum level with normal cardiac rhythm and VF induced after the implantation of an internal cardioverter defibrillator.

In this study entity was found that in 81% of the analysed OCA victims, the event was classified as recognised. Return of spontaneous circulation (ROSC) was achieved and survival to hospital discharge were 49% and 23%, respectively, if cardiac arrest was recognised and 40% and 16% when it was not. Dispatchers gave CPR instructions in 60% of the recognised OHA cases. Bystander-performed CPR increased over time and it was given in 58% of the recognised OHCAs but also in 17% of the events that were unrecognised.
Additionally, the EMS response time was shorter if OHCA was recognised as opposed to unrecognised (median response time 8 min vs. 9 min).

All the ECG recordings on the volunteers were correctly analysed when performed vertically at the mid-sternum level. The quality of the readings was good despite the ECG amplitude being approximately half that of the reference ECG amplitude, which was recorded with normal size defibrillation pads. From the recordings on the cardiac patients, the AED software correctly analysed all normal rhythms and 15 of 22 VF rhythms. The VF duration was too short for automatic detection in seven cases. The cardiologists analysed all the normal rhythms and VF sequences correctly and graded them as high quality.

The recognition of OHCA is vital for OHCA patients. It was associated with a reduced EMS response time, increased bystander rates of CPR administration, increased achieved ROSC rates and increased OHCA victims’ survival rates. For use in a rhythm-based OHCA recognition approach, the recordings of normal ECG rhythm and VF within an area the size of a mobile phone appear to have sufficient quality. This approach could strengthen the first links in the chain of survival and, thus, improve cardiac arrest outcomes.

Keywords: Cardiac arrest; Out-of-Hospital Cardiac Arrest; Heart arrest; Cardiopulmonary Resuscitation; Emergency Medical Services; Emergency Medical Communication Centre; Emergency Dispatching; Automated External Defibrillator; Mobile Phone; Ventricular Fibrillation; Survival
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TIIVISTELMÄ

Sydän ja verisuonisairaudet on maailmassa eniten kuolleisuutta aiheuttava sairausryhmä. Äkillisestä ja odottamattomasta sydänpysähdyksestä johtuvia kuolemia ilmenee vuosittain maailmanlaajuisesti 4 - 5 miljoonaa. Suomessa odottamattomia sairaalan ulkopuolia sydänpysähdyskä on noin 4300 vuodessa.


Hätäkeskuspäivystäjälle elottomuuden tunnistaminen hätäpuhelun aikana on haasteellista. Ennalta sovituilla, elottomuuden oireisiin suunnatulla kysymykyllä, pystytään tunnistamaan 50 – 80 % elottomuksista. Tunnistaminen saattaisi onnistua paremmi, mikäli käytettävissä olisi sydämen rytmiin perustuva elottomuuden tunnistusmenetelmä. Tässä menetelmässä matkapuhelimella ja siihen liitettyllä mobiiliteknologiailla sydämen rytmi rekisteröitään, analysoituu ja lähetetään hätäkeskukseen tulkittavaksi.

Tämän tutkimuskokonaisuuden tarkoituksena oli selvittää elottomuuden tunnistamisen merkitys sairaalan ulkopuolella tapahtuvan sydänpysähdykseksen ennusteeseen ja selviytymisketjuun perustuvia elottomuuden tunnistusmenetelmiä. Tämän lisäksi selvitetään matkapuhelimen kokoiselta alueelta matkapuhelimen rekisteröity transfusiologiasta käytettävää mobiiliteknologiaa EKG:n rekisteröintiin sekä elottomuuden tunnistamisen apuvälineena.

Helsingin yliopistollisen sairaalan sydänpysähdysten seurantarekisteristä poimittiin ja analysoitiin tiedot 2054 sairaalan ulkopuolella tapahtuvasta sydänpysähdyksestä. Lisäksi tutkimuksessa kartotettiin matkapuhelimen kokoiselta alueelta tallennettun EKG-rekisteröinnin laatua ja soveltuvuutta elottomuuden tunnistuksesta käytettävää mobiiliteknologiaa EKG:n rekisteröintiin sekä elottomuuden tunnistamisen apuvälineeksi. EKG rekisteröitiin 20 vapaaehtoisella koehenkilöllä neljästä eri kohdasta sekä elottomuuden eläkeläisten eli nssonan normaalin rytmin sekä normaalin normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elottomuuden normaalin rytmin sekä elotto


Avainsanat: sydämenpsyysähdyys; sairaalan ulkopuolinen sydämenpsyysähdyys; elottomuus; ensiapu; ensihoito; elvytys; hätäkeskus; hätäkeskuspäivystäjä; mobiililaitte; matkapuhelin; sydäniskuri; defibrillaattori; kammiovärinä; selviytyminen
“It always seems impossible until it’s done.”

Nelson Mandela
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Is this really the final chapter of this thesis? Am I finally writing the closing paragraphs of this undertaking, which at many times seemed never-ending? During the last decades, I have engaged in several scientific projects. They were didactic episodes of seemingly scientific and altogether curious episodes of my life. However, to transform one of those projects as a doctoral thesis, I needed an environment, motivation and energy that I simply did not have—or so I thought. Now, I am closer than ever to reaching an academic and personal milestone, the path to which, embarked upon in 2012, has been longer than I expected, quite rocky and full of ups and downs.

Looking back on the years passed, I realize that there is never an ideal time to begin such an undertaking in life. Something else always takes precedence, and anything can be an excuse not to rise to the challenge. For me, in the middle of my career, the time that I chose was somewhat late: a disadvantage—was it truly a disadvantage?—partly compensated by certain qualities that I would not have possessed as a younger man. Such qualities prove crucial to preparing scientific papers during the early or late hours of the day, beyond the time dedicated to professional obligations. With age, it becomes easier to be an early bird and wake up before anyone else; conversely, problems with falling asleep at night can be used to boost productivity.

Now, we are here. I say “we”, because this could not have been possible without the effort of the big squad of people around me. People who have encouraged, pushed and supported me at the right time.

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Joensuu, March 2019

Sakari Syväoja
LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications:


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<td>Automated External Defibrillator</td>
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<td>Electro Cardio Gram</td>
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<tr>
<td>ECMO</td>
<td>Extra Corporeal Membrane Oxygenation</td>
</tr>
<tr>
<td>EMCC</td>
<td>Emergency Medical Communication Centre</td>
</tr>
<tr>
<td>EMD</td>
<td>Emergency Medical Dispatch(er)</td>
</tr>
<tr>
<td>EMS</td>
<td>Emergency Medical Service</td>
</tr>
<tr>
<td>IABP</td>
<td>Intra-Aortic Balloon Pump</td>
</tr>
<tr>
<td>IHCA</td>
<td>In-Hospital Cardiac Arrest</td>
</tr>
<tr>
<td>OHCA</td>
<td>Out-of-Hospital Cardiac Arrest</td>
</tr>
<tr>
<td>PEA</td>
<td>Pulseless Electrical Activity</td>
</tr>
<tr>
<td>PUFA</td>
<td>Polyunsaturated fatty acid</td>
</tr>
<tr>
<td>ROSC</td>
<td>Return of Spontaneous Circulation</td>
</tr>
<tr>
<td>SCA</td>
<td>Sudden Cardiac Arrest</td>
</tr>
<tr>
<td>SCD</td>
<td>Sudden Cardiac Death</td>
</tr>
<tr>
<td>STEMI</td>
<td>Myocardial infarct with ST-elevation</td>
</tr>
<tr>
<td>VF</td>
<td>Ventricular Fibrillation</td>
</tr>
<tr>
<td>VT</td>
<td>Ventricular Tachycardia</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

As a class of illnesses affecting the heart or blood vessels, cardiovascular disease (CVD) is the primary cause of human death and a major cause of human disability around the world. Although CVD, especially ischemic coronary artery disease (CAD), was previously considered to be a problem of high-income or Western countries only, the greatest burden of the disease currently distresses low- and middle-income countries (Roth et al., 2017). Amongst the various outcomes of CVD, the crudest are out-of-hospital cardiac arrest (OHCA) and sudden cardiac death (SCD).

For decades, the survival rate of patients who have suffered from OHCA has remained low. Despite enormous investment in research and regularly updated guidelines to implement operational treatment chains for patients with OHCA, the overall survival rate remains at less than 10% (Sasson et al., 2010).

To optimise the possibility of surviving OHCA, resuscitation councils worldwide have implemented resuscitation guidelines not only in health and emergency services but amongst civilians, as well. Such efforts have revealed that two significant challenges in the treatment chain, or the ‘chain of survival’, are the recognition of emergency situations as cases of OHCA and the time-dependent nature of required operations in response (Viereck et al., 2017a, Valenzuela et al., 2000). In cases of OHCA, every minute without action deteriorates the patient’s likelihood of survival.

Ideally, the recognition of critical events as cases of OHCA in emergency medical communication centres (EMCCs) should result in the prompt dispatch of appropriate emergency medical service (EMS) units, instructions and encouragement for bystanders to perform cardiopulmonary resuscitation (CPR) and, in certain circumstances, the location and use of nearby automated external defibrillators (AEDs). If elements in the chain of survival work efficiently, then the survival rate of patients with OHCA can be increased (Buick et al., 2018). Indeed, communities that have put forth efforts to improve the performance of the chain of survival have shown increasing trends in the survival rates of patients with OHCA (Wissenberg et al., 2013, Chan et al., 2014, Ringh et al., 2015a).

The aim of the research reported in this thesis was to determine the impact of recognising cases of OHCA amongst EMCC dispatchers on the rate of the return of spontaneous circulation (ROSC), on the survival rate of patients with OHCA and on the chief elements in the chain of survival. After all, without the recognition of an OHCA event, no action will be taken in response. With that aim in mind, the research involved assessing the possibility of using mobile technology to support and enhance the process of recognising cases of OHCA.
2 REVIEW OF THE LITERATURE

2.1 OUT-OF-HOSPITAL CARDIAC ARREST (OHCA)

2.1.1 Definition and global burden of OHCA

In general, cardiac arrest refers to the cessation of cardiac mechanical activity, confirmed by the absence of signs of circulation (Jacobs et al., 2004). By extension, SCD, invariably caused by sudden cardiac arrest (SCA) in an in-hospital (IHCA) or OHCA setting, refers to natural death resulting from complications in the cardiovascular system. According to its widely accepted definition, SCD is denoted by the “abrupt loss of consciousness within 1 h of the onset of symptoms”. If SCD is unwitnessed, the definition also extends to “death occurring in normally functioning persons seen alive and well in the previous 24 h” (Farioli et al., 2015, Lopshire & Zipes, 2006). Due to differences in underlying causes of OHCA and the structure of care, epidemiological data for OHCA and IHCA are usually collected and reported separately (Writing Group Members et al., 2016).

Cardiac arrest is traditionally categorised as being of cardiac or non-cardiac origin. A case of cardiac arrest is presumed to be of cardiac origin unless rescuers determine the event to have been caused by trauma, drowning, drug overdose, asphyxia, exsanguination or any other non-cardiac cause (Jacobs et al., 2004). Current Utstein-style recommendations for reporting the aetiology of OHCA were recently revised to replace the category of cardiac origin from earlier Utstein-style recommendations with the category of medical origin (Perkins et al., 2015b). Often, the true aetiology of an OHCA event is difficult to determine. Historically, most (55–78%) of all reported cases of OHCA have been reported as having a presumed cardiac aetiology (Engdahl et al., 2003, Claesson et al., 2017). In a Swedish registry-based study of more than 70,000 cases of OHCA, 92% of the cases were categorised as medical and 8% as having a non-medical cause, often trauma (26%), drug overdose (24%) or drowning (11%) (Claesson et al., 2017). The Utstein-style recommended classification of cardiac arrest appears in Table 1.

<table>
<thead>
<tr>
<th>Primary cause</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical Cardiac arrest presumed to be caused by cardiac or medical reasons (e.g. anaphylaxis, asthma and gastrointestinal bleeding) but in which the exact cause is not obvious</td>
<td></td>
</tr>
<tr>
<td>Trauma</td>
<td>Cardiac arrest directly caused by blunt, penetrating or burn injury</td>
</tr>
<tr>
<td>Drug overdose</td>
<td>Cardiac arrest caused by deliberate or accidental overdose of prescribed medication, recreational drugs or alcohol</td>
</tr>
<tr>
<td>Drowning</td>
<td>Cardiac arrest presumed to be caused by submersion in water in the absence of alternative causation</td>
</tr>
<tr>
<td>Asphyxia</td>
<td>External causes of asphyxia (e.g. foreign-body airway obstruction, hanging or strangulation)</td>
</tr>
</tbody>
</table>

CVD remains a major cause of human health loss in all regions of the world. No longer solely a disease of high-income countries of the world, CAD is the leading cause of human death and a major cause of human disability due to non-fatal acute myocardial infarction, angina pectoris and ischemic heart failure worldwide. The global burden of CAD increased by 29% from 1990 to 2010 (Moran et al., 2014). This consisted of a 5% decrease of cases of CAD in high-income countries and an almost 60% increase of patients in low- and middle-income countries. Of particular importance is the fact that more than 25% of CAD cases in North Africa, the Middle East, South Asia and sub-Saharan Africa affect adults less than 50 years old—which are adults living the prime and most productive years of their lives (Moran et al., 2014, Gazzino et al., 2010).

Of the 53,670 deaths in Finland in 2017, 19,077 (36%) were attributed to CVD and, more specifically, 9,861 (18%) to CAD. Despite the considerable decline in deaths due to CVD from the rough rate of 1,300 per 100,000 deaths in 1970 to the current rate of 400 per 100,000, CVD and CAD remain the leading cause of human death in Finland (Suomen virallinen tilasto (SVT), 2018).
2.1.2 Factors modifying the risk of OHCA

Several demographic characteristics are risk factors of OHCA. For one, patients with OHCA are usually men, at a male-female ratio of approximately 60–70% to 30–40% (Morrison et al., 2016). Women are more likely to present with OHCA at home and less likely to have witnessed OHCA. Women also have a lower frequency of initial shockable heart rhythm, but they are more likely to receive CPR from bystanders. After adjusting for the aforementioned differences, women are also more likely to survive until hospital discharge (Bougouin et al., 2015). Moreover, the risk and incidence of OHCA markedly increase with age. For 50 year-old men, the annual incidence of SCD is about 100 per 100,000 compared to 800 per 100,000 for 75-year-old men (Becker et al., 1993). Amongst other demographic characteristics, lower socio-economic status, social isolation, psychological stress, anxiety and depression have been associated to increased cardiovascular mortality in various populations (Mensah et al., 2005, Rozanski, Blumenthal & Kaplan, 1999). Despite the indication of socio-economic and racial differences in the incidence of OHCA, it is difficult to separate socio-economic influences from true genetic predispositions (Gillum, 1997).

Certain pre-existing states of health are also risk factors of OHCA. Whilst most cases of OHCA in the population occur without an underlying inherited syndrome associated with SCD, the Framingham Heart Study, which continued for over half a century announced that pre-existing CAD was associated with a 1.9–5.3-fold increase in the risk of SCD and with a 1.5–6.2-fold increase in the risk of cardiac failure (Cupples, Gagnon & Kannel, 1992). CAD acts as a predisposition of OHCA and SCD in three general conditions: acute myocardial infarction, ischemia without infarction and structural alterations (e.g. scar formation, ventricular dilatation secondary to prior infarction and chronic ischemia) (Farb et al., 1995). CAD is responsible for roughly 75% of all OHCA and SCD, though it is the most common basis underlying SCD, followed by dilated cardiomyopathy and valvular heart disease (Deo & Albert, 2012). As such, approximately three quarters of people who die from SCA have underlying CAD, the consequence being that the standard risk factors for CAD can predict OHCA and SCD in the general population. Configurable risk factors of CAD, which have been proven to predict SCD, include hypertension, hypercholesterolemia, diabetes, kidney dysfunction, obesity and smoking (Balkau et al., 1999, Bhatt, Safford & Glasser, 2015).

On the other hand 5–10% of cases of SCD occur in the absence of CAD or other diagnosed heart disease. It is estimated that inherited arrhythmic disorders constitute approximately half of unexplained cardiac arrests (Krahn et al., 2009). Although such arrhythmic diseases are only a slight risk factor of SCD, they, to some extent, deserve attention. During the last decade, research focused on the genetic background of inherited arrhythmic diseases have provided insights into the heritability and electrical causes of heart diseases, such as long QT syndrome, Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia (VT) and short QT syndrome (Refaat, Hotait & London, 2015, Deo & Albert, 2012).

Research information has accumulated over the years and it seems that the risk of CAD can be modified. There is evidence that suggest that certain dietary patterns of multiple nutrients cause additive and interactive effects, which are associated with a reduced risk of SCD. In clinical trials, a Mediterranean-style diet consisting of vegetables, fruits, nuts, whole grains, fish and alcohol in moderate quantities and a low intake of red or processed meat, has been associated with the diminished risk of CAD (Sofi et al., 2010).

Various epidemiological studies have also proposed, stating that the increased consumption of polyunsaturated fatty acids (PUFAs) is inversely associated with SCD. According to a recent meta-analysis of randomised controlled trials, supplements of omega-3 PUFAs in patients with CAD is not associated with a protective effect on major cardiovascular events, although it has a favourable impact in reducing SCD and death, in general (Wen, Dai & Gao, 2014). However, whether currently available cardio-protective therapies for patients with CAD should include dietary supplementation with omega-3 PUFAs remains debated (Wen, Dai & Gao, 2014).

Alcohol and magnesium intake may also have an effect on the risk of SCD. Heavy alcohol consumption (>5 drinks/day) is associated with an increased risk of SCD, whereas reasonable consumption may decrease the risk (Chiuev et al., 2010, Wannamethee et al., 1995). Magnesium intake could also be inversely related to the risk of SCD (Chiuev et al., 2011, Peacock et al., 2010).
During the last decade, exposure to air pollution has been introduced as a risk factor for a variety of chronic diseases and CVD. Increased atherosclerosis, inflammation, rise in blood pressure and decreased heart rate variability originating from pollution can, thus, be related to SCA (Cho et al., 2018).

Risk of SCD in the population is a function of not only the underlying illness and its propensity to arrhythmia but also the excitability of the condition to triggers that aspire to increase sympathetic activity, which in turn, can expedite arrhythmia and SCD. Most studies have reported that inverse associations of increased regular physical activity with SCD and the benefits of exercise for general health are undeniable, though physical activity may also have adverse effects on the risk of SCD. Individuals who exercise on a regular basis have a favourable cardiovascular risk profile for CAD. Regular physical education can reduce their risk of myocardial infarction up to by 50%. However, intense exercise can infrequently trigger arrhythmia and SCD in athletes, who have an asymptomatic cardiac disease. Altogether, extreme training of physical performances previously considered to be unachievable may be associated with adverse electrical and structural remodelling in otherwise normal hearts (Sharma, Merghani & Mont, 2015).

Several studies have demonstrated a circadian pattern in the occurrence of SCD and OHCA. The incidence of SCD peaks in the morning, on Mondays and during the winter time. Such findings suggest that the onset of SCD may be associated with endogenous rhythms and external factors, including climatic conditions (Arntz et al., 2000).

And finally, the medical control is formed as an essential part of the risk prevention of vascular incidents in CVD patients. In higher income countries apart from hypertension and diabetes treatments, patients are usually medicated with antiplatelet agents, cholesterol lowering agents and angiotensin converting enzyme inhibitors to reduce major vascular events, deaths, and new diagnoses of diabetes (Antithrombotic Trialists’ (ATT) Collaboration et al., 2009, Giugliano et al., 2017, Bosch et al., 2005),. This kind of aggressive treatment can even reduce the size of CAD-formed vascular lesions (Puri et al., 2014).

“Abnormal lipids, smoking, hypertension, diabetes, abdominal obesity, psychosocial factors, consumption of fruits, vegetables, and alcohol, and regular physical activity account for most of the risk, over 90%, of myocardial infarction worldwide in both sexes and at all ages in all regions” (Yusuf et al., 2004). Although much has been clarified concerning the risk factors of CAD and SCD, much is yet to be researched. Amongst other things, established racial- and sex-based differences remain poorly understood. Risk stratification algorithms based on findings from epidemiologic studies evaluating traditional risk factors of CVD, lifestyle and dietary habits, biological markers and genetic variants, in combination, could aid in the identification of susceptible subgroups within the general population (Deo & Albert, 2012).

Table 2. Factors modifying the risk of OHCA

<table>
<thead>
<tr>
<th>HIGHER OHCA RISK</th>
<th>LOWER OHCA RISK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender male</td>
<td>Gender woman</td>
</tr>
<tr>
<td>Increasing age</td>
<td>Younger age</td>
</tr>
<tr>
<td>Smoking</td>
<td>Vegetables, fruits, nuts, whole grains, fish and alcohol in moderate quantities</td>
</tr>
<tr>
<td>High LDL cholesterol</td>
<td>Regular physical activity</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Magnesium intake</td>
</tr>
<tr>
<td>Obesity</td>
<td>Preventive medication (antiplatelet agents, cholesterol lowering agents, angiotensin converting enzyme inhibitors)</td>
</tr>
<tr>
<td>Diabetes</td>
<td></td>
</tr>
<tr>
<td>Inherited arrhythmic disease</td>
<td></td>
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<tr>
<td>Heavy alcohol consumption</td>
<td></td>
</tr>
<tr>
<td>Intake of red or processed meat</td>
<td></td>
</tr>
<tr>
<td>Lower socio-economic status, social isolation,</td>
<td></td>
</tr>
<tr>
<td>psychological stress, anxiety and depression</td>
<td></td>
</tr>
<tr>
<td>Air pollution</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td></td>
</tr>
<tr>
<td>Monday morning</td>
<td></td>
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</tbody>
</table>
2.1.3 Epidemiology and characteristics of OHCA

The incidence as well as survival rate of OHCA vary considerably amongst studies, continents, regions and countries. By definition, incidence refers to a measure of the probability of the occurrence of a given medical condition in a population (particularly that is at-risk) within a specified period (Noordzij et al., 2010). In the case of OHCA, incidence can refer to all patients who die outside a hospital, who die suddenly, who are attended by EMS or for whom resuscitation efforts were attempted. At the same time, the population at risk can be defined as, for example, all of the people in a region, only adults or only children, which could explain the exceeding variability of the reported incidence of OHCA. The activity of bystander-performed CPR can also affect its reported incidence, as can true variation in risk and treatment amongst regions.

In recent prospective studies drawing from multiple sources in the United States and Europe, rates of SCD have ranged from 50 to 100 per 100,000 per year in the general population (Fishman et al., 2010). Despite the need for multiple sources of surveillance to provide a more accurate estimate of the incidence of SCD, the overall burden in the population clearly remains high. Although improvements in primary and secondary prevention have resulted in substantial declines in overall CAD mortality in recent years, SCD has been reported to account for more than half of all deaths attributed to CAD (Fox et al., 2004, Gerber et al., 2006).

In their review of the global incidence of OHCA, Berdowski et al. noted a 10-fold variability in the incidence of OHCA amongst all studies considered. In their review, the global average rates of adult cases of OHCA attended to and treated by EMS were 96 and 62 per 100,000 person years, respectively. By continent, the respective rates were 113 and 51 in Australia, 98 and 47 in North America, 86 and 41 in Europe, and 53 and 46 in Asia (Berdowski et al., 2010). In a prospective single-month analysis of OHCA in Europe, the incidence of OHCA—84 per 100,000 people—was highly similar to that reported by Berdowski et al. (Grasner et al., 2016).

The results of the latter study added that the overall incidence of OHCA in which CPR was initiated was 49 per 100,000 patients, which is clearly higher than the rate previously reported for Europe 10 years ago (38 per 100,000) (Atwood et al., 2005).

In Finland in the latest study from the Pirkanmaa, an area with approximately 600,000 inhabitants, the EMS attended OHCA incidence was 52/100 000 inhabitants per year and the EMS attempted resuscitation on 47/100 000 inhabitants per year (Setälä et al., 2017). In southern and eastern Finland in 2010, according the Finnresusci study, EMS contemplated resuscitation for 78 patients with OHCA per 100,000 inhabitants per year and attempted resuscitation on 51 per 100,000 annually (Hiltunen et al., 2012). In earlier studies from Finland, the estimated rates of considered resuscitation were 94, 80 and 113 per 100,000 inhabitants (Kämäräinen et al., 2007, Kuisma & Määttä, 1996, Silfvast, 1990).

In Europe according to the EURECA study, most cases (69%) of OHCA occurred at residence and 66% of the events were witnessed (Grasner et al., 2016). In the Finnresusci study, nearly 70% of events of cardiac arrest occurred at home or in extended care facilities compared to 23% in public places. Bystanders and EMS witnessed 68% and 21% of the events, respectively, whereas 9% of events were not witnessed (Hiltunen et al., 2012).

Last, in recent decades, the incidence of ventricular fibrillation (VF) as the initial recorded heart rhythm in patients with OHCA has declined (Cobb et al., 2002, Hulme et al., 2015, Väyrynen et al., 2011). During the last 10 years, the initial heart rhythm of EMS-treated patients with OHCA has been shockable in 20–31% of cases (Nichol et al., 2008, Benjamin et al., 2017, Hiltunen et al., 2012).

2.1.4 Prognosis of OHCA

The reported prognosis of patients with OHCA for any reason and without any specific subgroups has been stated to be poor and unchanging during recent decades (Sasson et al., 2010). Despite steady research, new drugs and devices and periodic evidence-based revisions to clinical guidelines, the survival rate of patients with OHCA has not improved in nearly 30 years; as aggregate data recorded across various populations have indicated, it hovers between 6.7–8.4% (Sasson et al., 2010). The lack of change could partly stem from the declining incidence of VF arrests, the increasing age of the general population and longer average response times of EMS due to population growth and urbanisation (Herlitz et al., 2004, Cobb et al., 2002, Hulme et al., 2015).
In samples of patients with OHCA selected according to their primary heart rhythms, survival rates have been particularly low; however, in certain circumstances where bystanders witness the event, the primary rhythm is VF and the fibrillation is promptly performed, survival has been shown to be likely and even expected (Valenzuela et al., 2000, Pollack et al., 2018, Okubo et al., 2017). Furthermore, despite previous scepticism towards the practice, critically assessing and improving the local chain of survival of patients with OHCA seem to have boosted their rates of survival rates in recent years (Wissenberg et al., 2013).

Traditionally, non-shockable rhythms, asystole (ASY) and pulseless electrical activity (PEA) have been associated with poor prognoses. Such non-shockable rhythms are often the final result of the progression of shockable rhythms and, in certain forms of traumatic cardiac arrest and asphyxia, the initial rhythms of OHCA. As mentioned earlier non-shockable rhythms, unfortunately, currently dominate also amongst patients with OHCA of presumed cardiac origin upon receiving treatment from EMS, whereas the number of shockable rhythms, hence those with better prognoses, as the initial or primary rhythms have decreased (Cobb et al., 2002). Amongst possible causes of the increasing dominance of non-shockable rhythms, the vast majority of patients with CAD are widely diagnosed and medicated with beta-blockers, which are presumed to reduce the incidence of VF as the initial rhythm in patients with OHCA (Youngquist, Kaji & Niemann, 2008). By extension, the downward trend of untreated CAD as a cause of SCA could partly explain the upward trend of ASY and PEA as the initial heart rhythms of patients with OHCA. Amongst patients with non-ischemic cardiac disease, ASY and PEA are reported to be more common presenting rhythms than VT or VF at the time of SCA (Kauppila et al., 2018).

In an Australian study of 11,973 cases of OHCA with non-shockable initial rhythms in which EMS was attempted, only 1.1% of patients with OHCA who had ASY and 5.9% who had PEA survived until hospital discharge; no significant improvement in either rate was observed during the 10-year study period. (Andrew et al., 2014).

In Finland, the rate of survival to hospital discharge of patients with OHCA who initially presented with ASY is approximately 3-4%, whereas that of patients who presented with PEA is 6–10% (Värynen et al., 2008a, Saarinen et al., 2012, Värynen et al., 2008b).

OHCA due to trauma has been associated with ASY and PEA rhythms, and prognoses in those cases have typically been bleak. However, reported survival rates of patients with trauma-induced cardiac arrest have recently improved, compared to rates of patients with non-shockable rhythms stemming from any cause. As responses to OHCA have become more active, protocols for treating traumatic arrest have been introduced to address reversible extra-cardiac causes of OHCA (Smith, Rickard & Wise, 2015, Deasy et al., 2012).

Despite modest prognoses for OHCA with non-shockable rhythms, patients with those rhythms represent approximately 75% of all cases of OHCA and, thus, also a significant proportion of all survivors (Kuisma & Määttä, 1996). Thus, a reduced likelihood of survival cannot be equated to a lack of change (Chamberlain, 2010).

In the United States, The Cardiac Arrest Registry to Enhance Survival (CARES) was introduced in 2004 to help communities determine standard outcome measures for OHCA and allow for quality improvement efforts and benchmarking capabilities to improve care and increase survival (McNally et al., 2011). According to this registry, the risk-adjusted rate of OHCA survival to hospital discharge increased from 5.7% in 2005–2006 to 8.3% in 2012 (Chan et al., 2014). In the latest CARES report published in 2018, of the 76,215 non-traumatic cases of OHCA evaluated, 18% involved shockable rhythms, 32% ended with sustained ROSC, and 28% involved admission to a hospital. Survival to hospital discharge was 10.4%. Good neurological function—that is, Cerebral Performance Category (CPC) of 1 or 2—was found in 80% of the patients. For cases of bystander-witnessed arrest with a shockable rhythm (i.e. Utstein-recommended comparator group reflecting system efficacy), the rate of survival to hospital discharge was 33%. If bystander-performed CPR was administered for the patient following witnessed arrest with a shockable rhythm, the rate of survival to hospital discharge was 37% (CARES Summary Report, Demographic and Survival Characteristics of OHCA, 2018).

For Europe, a picture of the prognosis of OHCA can be drawn from the results of the European Registry of Cardiac Arrest project, which determined the incidence, processes and outcomes regarding OHCA in numerous European countries (Grasner et al., 2016). The project was an international, prospective, multi-
centre, single-month study designed as an initial step to establish the European Registry of Cardiac Arrest. In the evaluation, ROSC was achieved in 29% of patients, and overall rate of survival to hospital discharge was 10.3%, albeit with wide divergence in national rates. Mean survival rate following bystander-witnessed arrest probably of cardiac origin with a shockable heart rhythm was 30%, with a range of 5.3–58% (Grasner et al., 2016).

In Finland, the survival rates of patients with OHCA have been evaluated five times since 1987. In reports by Silfvast and Kuisma et al. from Helsinki from 1987, 1994 and 2004, survival rates of witnessed cases involving an initial shockable rhythm were 27%, 34% and 35%, respectively (Silfvast, 1990, Kuisma & Määttä, 1996, Kuisma et al., 2005). For comparison, in a 2007 study by Kämäräinen et al. in Tampere, it was 29% (Kämäräinen et al., 2007). In 2010, the Finnresusci study revealed that any degree of ROSC was achieved in 44% of patients and that the rates of survival from all events involving any heart rhythm to hospital discharge and to a year after the incident were 20% and 13%, respectively. Of patients whose initial rhythm was shockable and whose event was witnessed, 46% survived to hospital discharge (Hiltunen et al., 2012). In an evaluation of 314 OHCA events with attempted CPR in Pirkanmaa during 2013-2014, the overall survival to hospital discharge was 14%. When the primary rhythm was shockable and the event witnessed, the survival rate was 33% (Setälä et al., 2017). Thus, the rate of survival for patients with OHCA in the patient group with shockable rhythm seems to have an improving trend in Finland.

2.1.5 Utstein style: Reporting the science of OHCA

As in most branches of science, the difficulty of comparing and interpreting the results in resuscitation science partly stems from the diverse definitions of terms used in studies and reports. As a case-in-point, reports of resuscitation science often include the term Utstein style or Utstein-style reporting. In either case, the term refers to a uniform reporting template, which is derived from consensus-based reporting guidelines for resuscitation. This template took its origin at an international multidisciplinary meeting, which was held near Stavanger at Utstein Abbey, Norway, in June 1990 (Cummins et al., 1991a). The purpose of the meeting was to develop uniform terms and definitions for out-of-hospital resuscitation in order to support clinical research and facilitate intra- and intersystem comparisons. Since their establishment, the guidelines have been revised sporadically, most recently in 2014 (Perkins et al., 2015b). The template consists of core and supplemental data elements in five categories: EMS system, dispatcher, patient, process and outcome (Table 3).
Table 3. The Utstein template to report results in resuscitation science. Adapted and modified from Perkins et al., 2015b. CA, cardiac arrest; CPR, cardiopulmonary resuscitation; AED, automated external defibrillator; ROSC, return of spontaneous circulation; DNAR, do not attempt resuscitation; STEMI, myocardial infarct with ST-elevation; BP, Blood pressure; ECMO, extra corporal membrane oxygenation; IABP, intra-aortic balloon pump

<table>
<thead>
<tr>
<th>System</th>
<th>Dispatcher</th>
<th>Patient</th>
<th>Process</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORE</td>
<td>Population served</td>
<td>Dispatcher-identified CA</td>
<td>Age</td>
<td>Response time</td>
</tr>
<tr>
<td></td>
<td>Cardiac arrest attended</td>
<td>Dispatcher CPR instructions</td>
<td>Gender</td>
<td>Defibrillation time</td>
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<td>Resuscitation attempted</td>
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<td>Witnessed arrest</td>
<td>Target temperature management</td>
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<td>Resuscitation not attempted</td>
<td></td>
<td>Arrest location</td>
<td>Drugs</td>
</tr>
<tr>
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<td>System description</td>
<td>Bystander-performed</td>
<td>CPR or AED</td>
<td>Reperfusion attempted</td>
</tr>
<tr>
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<td>First monitored rhythm</td>
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<td></td>
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<td>Aetiology</td>
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<td>DNAR legislation</td>
<td>Independent living</td>
<td>Airway control type</td>
<td>Survived event</td>
</tr>
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<td>Termination of resuscitation rules</td>
<td>Comorbidities</td>
<td>Number of shocks</td>
<td>Any ROSC</td>
</tr>
<tr>
<td></td>
<td>Dispatch software used</td>
<td>Presence of STEMI</td>
<td>Drug timings</td>
<td>Survival to discharge or 30-day survival</td>
</tr>
<tr>
<td></td>
<td>Resuscitation algorithms followed</td>
<td>Ventricular assistive devices</td>
<td>CPR quality</td>
<td>Neurological outcome</td>
</tr>
<tr>
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<td>Data quality activities</td>
<td>Cardioverter defibrillator</td>
<td>Vascular access type</td>
<td></td>
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<td>Mechanical CPR</td>
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<td>Targeted oxygenation, ventilation or BP</td>
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<td>12-month survival</td>
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The implementation of the recommendations has encouraged the development of other consensus-based guidelines similar to those of Utstein style but also considering paediatric advanced life support, laboratory research, in-hospital resuscitation, education, drowning, post-resuscitation care and emergency medical dispatch (Castren et al., 2008, Perkins et al., 2015b).
2.2 EMERGENCY MEDICAL SERVICE (EMS) AND CARDIOPULMONARY RESUSCITATION (CPR)

2.2.1 History and development of EMS

The EMCC is tasked with ensuring the safety of people in surrounding communities. EMCCs dispatch professional help to the scene after a rapidly conducted risk analysis of emergency notifications that consider social, medical, rescue or police involvement, as well as issues instructions to callers to initiate immediate first aid to patients if applicable (Räsänen & Kuisma, 2010, Roppolo et al., 2005). EMCCs and emergency medical dispatchers (EMDs) thus are the first link in the chain of Emergency Medical Services (EMS) and stand at the gateway of further medical assessment and treatment (Torlen et al., 2017, Castren et al., 2008, Clawson, Martin & Hauert, 1994). However, the ways in which EMCCs are organised in different countries, and sometimes even within countries vary significantly (Fischer et al., 2011). Major changes at EMCCs in recent years, often due to external factors (i.e. limited resources, need to control costs and debate concerning management responsibilities), have affected their development and success (Langhelle et al., 2004, Lindstrom et al., 2011, Pozner et al., 2004).

2.2.1.1 Progress of prehospital EMS

One of the earliest descriptions of the organised treatment of pre-hospital injuries and illness took place during the Italian campaign of the French Revolution in 1794. Baron Dominique Jean Larrey (1766–1842) was a French surgeon in Napoleon’s Grande Armée and an important developer and innovator in battlefield medicine and triage. He recognised that allowing wounded and faint soldiers to remain on the battlefield for days without treatment increased both their morbidity and mortality. As a response, he instituted an organisation in which trained medical personnel initiated the treatment in the scene and transported the wounded to a field hospital. During the US Civil War, after the Second Battle of Bull Run in August 1862, thousands of Union soldiers lay wounded on the battlefield for days before any medical treatment was initiated. This clearly contributed to their high mortality. Consequently, military surgeon Jonathan Letterman applied Baron Larrey’s concepts to create the first organisation in the United States to treat and transport injured patients. Soon after Letterman’s activity, the civilian community recognised the importance of an EMS system. In 1865, the Commercial Hospital of Cincinnati developed the first civilian ambulance service (Pozner et al., 2004). Bloody wars on the European continent, as in North America, stimulated not only the establishment of ambulance and emergency medical services for the military as well as for civilians but also non-governmental volunteer first aid organisations such as the Red Cross and the Order of Malta (Bossaert & Chamberlain, 2013).

Despite the development of the EMS system through the first half of the 20th century, most ambulances were hearses from local funeral homes that transported patients to hospitals instead of morgues (Pozner et al., 2004). After 1950, the evolution of EMS made a major leap when two civilian physicians, JD Farrington and Sam Banks, arranged a first-aid training programme for the Chicago Fire Department. Their system became the prototype for the first basic emergency medical technician training programme in the United States. Concurrently, as the pathophysiology ofVF and VT become clearer, the defibrillation of those shockable rhythms became possible. In Belfast, Northern Ireland, Frank Pantridge modified the defibrillator into a portable device. He organised a regime that used a mobile emergency medical unit that enabled defibrillation and intensive care at the scene (Pantridge & Geddes, 1967).

Today, every country in Europe and many countries throughout the world provides pre-hospital EMS as a unique component of their emergency healthcare systems. Although their various services have numerous similarities, no common European or US standard for EMS exists.

In Finland, the evolution of the EMS system has followed the trends and blueprints of EMS in other European countries and the United States. Wars and military need for emergency services were the primary catalysts of the Finnish EMS system’s birth and development. Procedures adopted on the battlefield were later replicated and applied to meet civilian needs. The first ambulance for the pre-hospital management of wounded soldiers was dispatched from Finland during the Russo-Turkish War by the recently founded
Finnish subdivision of Red Cross in 1877. That so-called ambulance, actually a field hospital with 50 beds, nevertheless received the first notice for its remarkable efforts in pre-hospital care in the Finnish EMS context (Suomen Punainen Risti, 2018). During the first half of the 20th century, wars in which Finland participated, including World War I, the Finnish Civil War and the Winter War and the continuation War during the years of the World War II, formed the basis upon which Finnish pre-hospital care progressed in post-war decades. At the beginning of the 1950s, however, the organisation of the pre-hospital transport of sick or injured people remained undeveloped and haphazardly organised. Following the initial regulations of the Finnish Ministry of Health concerning the minimum equipment needed by ambulances in 1956, the EMS system in Finland achieved its generally accepted role in the healthcare regime and received the facilities to develop more efficiently (Järvinen, 1998).

Currently emergency medical physicians also are a part of the EMS on the field. The “cardiac ambulance model of Belfast” with an emergency medical physician on board was replicated and tried in Helsinki in 1971, and the formal action was initiated in 1972. This type of physician on board as well as mobile intensive care unit (MICU) attempts were also realised in Oulu, Kajaani and Kuopio in the late 70s. However, the only community- or municipality-maintained ambulance unit continued to operate only in Helsinki (Järvinen, 1998).

Helicopter EMS, which is also staffed with an emergency physician, commenced in 1992 in Finland. This operation extended from Helsinki and Turku to Oulu and Kuopio and was strongly charity- or grant-based until 2012. After that, the responsibility of the funding of the HEMS operation has been on the government.

2.2.1.2 Evolution of the Emergency Medical Communication Centres (EMCCs) in Finland

At the beginning of the evolution of EMCCs, the role of dispatchers was simply to serve as an intermediary between transporters and patients. However, the roles of EMCCs and dispatch centres have concurrently evolved with the roles of ambulances, emergency medical technicians and paramedics. The roots of today’s EMCC organisation are in the legislation settled in 1991 and 1993. It considered the possibilities of interconnected communication and dispatch centres for police, rescue and medical emergencies as an Emergency Communicating Centre (ECC), as well as of expanding the geographical areas that the centres served. After an experimental period during 1996–2001, the Finnish government-maintained ECC organisation was founded in 2001. As the consequence of the shift of responsibility from municipalities to the national government, the number of local ECCs was first reduced to 15 and later in 2011 to six centres. The downgrade was extensive; before the renovation, 58 municipalities maintained telephone network-based regional communicating centres prescribed by legislation in 1976. Aside from changes in the organisational structure, the role of the ECC dispatchers also changed in time. Whereas they once managed narrower segments of police, rescue or medical services, they gradually required the professional ability to serve all such segments, which necessitated the resumption and improvement of education and training for dispatchers. Provided since 1997 in collaboration with the Emergency Services College in Kuopio and the Police University College in Tampere, Finland’s education and training programme for emergency response centre operators and EMDs takes 1.5 years to complete (Hätäkeskuslaitos, 2011, Lindström et al., 2011).

In 2017, emergency response centre operators answered 2.68 million emergency calls, or approximately 6,100 emergency calls and a total of 8,400 calls per dispatcher, with a response time of less than 10 s in 93% of cases. Slightly more than half (1.35 million) of the calls were forwarded to the appropriate authority. The emergency calls transmitted were considered to be EMS in 55% (742,500 calls) of cases, police issues in 36%, fire or rescue issues in 6% and social emergencies in 3%. Amongst reasons for emergency calls, cardiac arrest justified approximately 0.16% of calls (4300 OHCA calls per 2.68 million calls) and 0.6% of the EMS-transferred emergency calls. In response to OHCA events, the first unit was dispatched within 90 s in 69% of cases (Hätäkeskuslaitos, 2018).

In Finland, 000 was used as the common emergency number since 1983. After the European Union adopted 112 as the common emergency number on 29 July 1991, Finland followed suit in 1993.
2.2.2 History of CPR

2.2.2.1 Artificial ventilation

Although frequent reports of successful medical efforts to resuscitate patients did not appear until the early 19th century, resuscitation processes have evolved over many centuries, with the first accounts dating back to Biblical times. The first mention of possible artificial ventilation and first documented recitation of life support appears in the Old Testament (LaHood & Moukabary, 2009). In Kings 2, it describes the resuscitation of a young boy by the prophet Elijah: ‘And he [Elijah] went up, and lay upon the child, and put his mouth upon his mouth, and his eyes upon his eyes, and his hands upon his hands: and he stretched himself upon the child; and the flesh of the child waxed warm’ (4:34).

In more certain designation, airway and breathing control are described in the Babylonian Talmud. In the 6th-century collection of Jewish oral narratives, a lamb with a neck injury was saved by punching a hole in the trachea and supporting airflow with a hollow reed placed therein. That technique with similar designs was reintroduced a millennium later by Belgian anatomist Andreas Vesalius (1514–1564). However, knowledge of the tracheostomy-cum-intubation practise lay quiescent until the 18th century due to a hesitation for its propriety and applicability to humans. In 1768, the Dutch Humane Society created and released resuscitation guidelines to aid citizens who had drowned in waterways. These guidelines focused on clearing the inhaled water from the trachea and airways by rolling patients on a barrel or dangling them upside down. Endotracheal cannula were also used to afford access to the airway. Some years later, in 1889, Sir Henry Head introduced the cuffed endotracheal tube, and in 1895, Alfred Kirstein invented the laryngoscope to ease the visualisation of the larynx (Cooper, Cooper & Cooper, 2006).

Efforts to achieve artificial breathing accompanied the management of artificial airways. Nostril ventilation with fireside bellows was first mentioned by the ‘father of toxicology’, Paracelsus, in the 1500s. Early mouth-to-mouth ventilation was described by British surgeon William Tossach, who used the technique during the resuscitation of a coal miner in 1732. However, using exhaled air for resuscitation was abandoned after the discovery of oxygen (1772) by Swedish chemist Carl Sheele. Exhaled air, to be used during mouth-to-mouth ventilation, became known as toxic or devitalised. In response to that, other means of artificial ventilation were sought. From 1850 to 1860, Marshall Hall and Henry Robert Silvester advanced artificial ventilation by placing pressure to the chest and arm-lift practices in supine patients. Their method of relieving asphyxia was largely practiced in variations until the 1960s and even amid the rise of modern CPR (Cooper, Cooper & Cooper, 2006).

2.2.2.2 Chest compressions and circulation

The early strategy in resuscitation was the support of respiration, which was based on the experiential fact that the action of the heart copies the starting and stopping of ventilation. Although the palpation of pulses had been known for hundreds or thousands of years, in 1874, Moritz Schiff noticed that manually pressing the canine heart in an open thorax produced a carotid pulsation. Soon after, the same effect was observed when external pressing was administered to the sternum and ribs. In 1892, Friedrich Maass reported the first successful closed-chest cardiac massage. Unfortunately, his successful approach was forgotten or else dismissed for nearly 70 years. In 1901, at the Tromso Hospital in Norway, Kristian Igelsrud performed the first successful direct heart compression after an anaesthesia-induced cardiac arrest. For the next 50 years, SCA was thought to be successfully managed only in operating theatres or other venues where open cardiac massage was possible to perform (Cooper, Cooper & Cooper, 2006). Eventually, the new dawn of closed-chest cardiac massage occurred in the late 1950s. At that time, Maass’ ideas from 1892 were reconsidered by William Kouwenhoven, James Jude and Guy Knickerbocker (Kouwenhoven, Jude & Knickerbocker, 1960).
2.2.2.3 Defibrillation

The roots of defibrillation reach back to 1775, when Peter Christian Abildgaard, a Danish veterinarian and physician, conducted experiments on electrical counter-shock on animals (Driscoll, Ratnoff & Nygaard, 1975). He managed to cause chickens to be lifeless by electric shock and later revived them by counter-shock applied to the chest. At the time, Abildgaard was unaware of the effects of electrical shock on the heart and considered that the shocks non-specifically stimulate unconscious patients. Later, in 1850, German physician Carl Ludvig described electrically induced quivering or defibrillation of the heart as a curiosity. In 1889, Drs. Louis Prevost and Frederic Batelli in Geneva noticed that repeat shock or counter-shock could restore the contractions of the fibrillating heart (Cakulev, Efimov & Waldo, 2009). At the same time, William Einthoven, later Nobel Prize winner in medicine, introduced the first practical registration of the electrocardiogram (ECG), which allowed the non-invasive recording of heart rhythms and, accordingly, accelerated research on dysrhythmias (Cajal & Varon, 2008).

The work of Prevost and Batelli inspired, amongst others, Carl Wiggers, whose experiments on dogs exposed the different stages of VF and greatly improved defibrillation techniques. In 1947, surgeon Claude S. Beck, who was familiar with Wiggers and practiced at the university hospital next door to him, performed the first successful open-heart defibrillation using Wiggers’ defibrillation machine. After around one hour of open cardiac massage and two series of electrical shocks, a regular pulse was restored without neurological consequences (Cooper, Cooper & Cooper, 2006). In 1955, the first successful closed-chest defibrillation was performed by Paul Maurice Zoll (Zoll et al., 1956). Later, in 1962, Bernard Lown noticed that the direct-current waveform, later named the ‘Lown waveform’, was effective in defibrillation and far less damaging to the heart than the alternating current used in early defibrillators (Lown, Amarasingham & Neuman, 1962). As the technique rapidly gained popularity in the 1960s and 1970s, the Lown waveform became the standard for defibrillation until it was superseded by the biphasic truncated waveform in the 1990s.

As in many fields of life, research and technology, communication about resuscitation science between the West and East was victim to the Cold War, Iron Curtain and language barriers. In the former Soviet Union, resuscitation medicine, or reanimatology, which included the prevention and treatment of critical terminal and post-resuscitation states, had a long tradition (Safar, 2001). In 1936, the father of reanimatology, Vladimir Negovsky, founded and organised the first resuscitation research laboratory in the Soviet Union. Negovsky and his colleagues studied acute life-threatening conditions, especially the pathophysiology and the treatment of terminal states that were caused by different trauma, blood loss, myocardial infarction, drowning and asphyxia. Negovsky’s associates Naum Gurvich and SG Yuniev, who had worked on defibrillation since the 1930s independently of Western scientists, developed a version of the defibrillator that became used widely in the Soviet Union (Safar, 2001). The development of the closed-chest defibrillator using externally applied electrodes was pioneered not only by Zoll in the Western world but also by Dr. V. Eskin and Dr. A. Klimov in the Soviet Union. In the late 1960s, the biphasic waveform model for defibrillators was also developed and introduced by the Soviet investigators (Cakulev, Efimov & Waldo, 2009).

2.2.3 Dispatchers as part of EMS

EMDs function as the first link between emergency callers and EMS. Although their role was once roughly similar to that of telephone operators, today’s EMDs rank amongst the leaders and managers of the entire EMS system (Rossi, 1994).

The role of EMDs involves questioning callers of emergency phone calls, identifying the need for EMS, determining the priority of the event in question, allocating appropriate, albeit often limited, EMS resources and issuing instructions or initiating immediate first aid, if not both, for the patient via bystanders (Bailey, O’Connor & Ross, 2000, Castren et al., 2008). In the case of OHCA, the recognition of cardiac arrest by EMDs improves the survival of patients (Viereck et al., 2017a), and when OHCA is not recognised, the survival rate of patients experiencing OHCA decreases (Berdowski et al., 2009). The necessary responses of EMDs to OHCA include the prompt dispatch of EMS and EMD-assisted or -instructed bystander-performed CPR over the phone, the latter of which, when initiated early, improves the likelihood of survival (Cummins et al., 1985,
In a study from Sweden, bystander-performed CPR increased the survival for one month by two to three times, and the VF rate was 10–15% higher amongst patients who received bystander-performed CPR (Holmberg, Holmberg & Herlitz, 2000). In their meta-analysis, Sasson et al. reported similar findings; bystander-performed CPR as well as VF, presented as the initial heart rhythm, increased the survival of patients with OHCA (Sasson et al., 2010).

The nature of the EMD occupation is demanding and under the continual screening of authors and the general public. EMDs are expected to accurately consider the priority and all other aspects of the dispatch process time after time. As mentioned, medical dispatch philosophies have evolved to standardise, improve and enhance the dispatch process. Today, the two most often used concepts, as well as their modifications, for EMDs to judge and manage emergency situations are medical priority dispatch and criteria-based dispatch (Hardeland et al., 2014). The essential difference between the concepts lies in whether EMDs should follow strict protocols or somewhat looser guidelines (Clawson, Martin & Hauert, 1994). Although both concepts have various advocates, the superiority of one over the other rests more with the opinions of authority than with evidence (Culley et al., 1994, Clawson et al., 2008a, Hardeland et al., 2014). When selecting a medical dispatch programme for a local EMCC, the cultural and educational backgrounds of EMCC personnel should thus be considered (Dami et al., 2010).

In Finland, the dispatch protocol has attributes of both concepts. Since the 1980s, Finnish EMS dispatchers have used four priority codes, from A (i.e. highest risk) to D (i.e. lowest risk), to represent the urgency of the patient’s condition after the assessment of the situation. To support the assessment process, EMDs use the national assessment guidebook with criteria for the medical priority of chief complaints (Lindström et al., 2011, Hoikka et al., 2016). The priority codes for EMS dispatch in Finland include the following:

- **Priority Code A**: The patient has a life-threatening condition or has been exposed to a high-energy accident. The emergency call should be responded to immediately. The nearest ambulance and, in certain events, the physician unit should be dispatched to the scene.
- **Priority Code B**: There is suspicion of failure of vital functions. The emergency call should be responded to immediately, and the nearest ambulance should be dispatched to the scene immediately.
- **Priority Code C**: The patient needs assessment by an emergency care team. The ambulance must arrive at the scene within 30 min.
- **Priority Code D**: No suspicion of failure of vital functions. The patient can wait, although the ambulance must arrive at the scene within 120 min.

EMS systems and systems for EMDs have been developed in diverse ways in different countries. Selecting the best practices and effective interventions to improve modes of operation has been difficult, however, given the lack of standardised terms used and of standardised ways of reporting the results of emergency medical dispatch science. In 2005, by defining a uniform reporting system for both EMCCs and EMDs, an important step was taken to highlight the importance of that part of the pre-hospital care of patients that today enables the comparison of results for research and quality-assurance processes within countries and internationally (Castren et al., 2008).

For a comparison of EMCCs to be valid, it is necessary to determine universal trigger points that constitute general parts of the processes at EMCCs, regardless of how the EMCC and surrounding services have been organised. The process for a dispatch service can be summarised as encompassing sequential events (Table 4) (Castren et al., 2008).
Table 4. The core and supplemental response points of the dispatch process. Adapted and modified from the article of Castren et al., 2008.

<table>
<thead>
<tr>
<th>Public response interval</th>
<th>Core data</th>
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<tbody>
<tr>
<td>1. The incident occurs.</td>
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<tr>
<td>2. The emergency call is made.</td>
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<table>
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<tr>
<th>EMD response interval</th>
<th>Core data</th>
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<td>3. The call is answered by the service.</td>
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<td>4. A need is identified.</td>
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<td>5. A priority is decided.</td>
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<td>6. A response is defined.</td>
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<tr>
<td>7. The response or resource is dispatched.</td>
<td>Core data</td>
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<tr>
<td>8. Assistance may be given online, if indicated.</td>
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<tr>
<td>9. The call is terminated.</td>
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### 2.2.4 EMS in the future

As Niels Bohr famously said, “Prediction is very difficult, especially about the future”. EMS systems around the world are in different stages of development. Whereas younger organisations are striving to attain the level of efficiency and quality of high-income countries, the healthcare organisations and structures in those high-income countries are either at a turning point or will be in crisis. Medical facilities and developments to help people and increase the length and quality of life are evolving at an accelerating pace, whilst the social resources to purchase those new technologies are limited and, thus, present challenges to maintaining current infrastructure and facilities. As populations move to urban areas, they leave large areas uninhabited or else rural. Although the resulting centralisation is desirable from the perspective of healthcare organisers because it reduces the need to maintain infrastructure and services, the situation in rural areas raises the question of what kinds of services are reasonable for areas where the density of residents is low.

In the future, the density of EMS coverage and the spatial distribution of emergency hospitals in rural areas will shape the role of EMS. It is possible that EMS organisations will have to assume greater responsibility for patient care due to longer transport distances and transfer times. At the same time, more treatments currently performed at hospitals could need to be performed in patients’ homes or ambulances. As a result, EMS will need to carry more equipment and more specialised equipment, as well as point-of-care tests—for example, mobile technology for brain imaging and the management of acute stroke (John et al., 2016). The role of trained volunteer first responders as a supplement to the existing emergency response systems of the EMS is a considerable idea in certain circumstances. In a concurrent development, traffic density and rush hours in expanding urban centres have already exacerbated EMS response times, which could increasingly jeopardise services that rely upon EMS support (Chen et al., 2015, Sladjana, Gordana & Ana, 2011, Griffin & McGwin, 2013, Ono et al., 2016). Ideally, omnipresent information technology will cover, protect and measure patients as well as EMS in the future (Tan et al., 2017). In the dispatch process, mobile devices and measurements will likely assume a major role in the assessment of patients in order to support EMDs in their work.
2.3 CHAIN OF SURVIVAL OF PATIENTS WITH OHCA: OBJECTIVES AND CHALLENGES

Figure 1. Chain of Survival.

Since its foundation in 1988, the European Resuscitation Council (ERC) has advised resuscitation practice across Europe with guidelines, published in 1992 and revised in 1998, 2000, 2005, 2010 and 2015, that are accepted in most of Europe as the standard of care and a reference for clinical practice (European Resuscitation Council, 2018). In the decades prior to its foundation, Fritz Ahnefeld introduced the universal concept or metaphor of the chain of survival (‘die Rettungskette’) of OHCA in Germany in 1967 (Ahnefeld et al., 1967). In March 1981, Ahnefeld’s vision was published for an intercontinental audience in the newsletter of CPR for Citizens in Orlando, Florida, after which Mary Newman expanded awareness of the concept of chain of survival throughout the late 1980s (Newman, 1989). In the early 1990s, the American Heart Association and the International Liaison Committee on Resuscitation (ILCOR) added the concept to their guidelines, as did the ERC and other members of the ILCOR, all to improve the outcomes of patients with cardiac arrest. To this day, the chain of survival concept summarises the vital links needed for successful resuscitation following cardiac arrest (Nolan, Soar & Eikeland, 2006, Cummins, 1993).

2.3.1 Early recognition and call for help

In the chain of survival for patients who are experiencing cardiac arrest, the first step is twofold: early recognition of the event and, in response, calling for help. The objective of the step is twofold as well: to recognise chest pain or another warning sign of cardiac origin as early as possible and call emergency services before cardiac arrest has occurred. Completing both objectives is vital to improving the odds of surviving the event (Takei et al., 2015). Quite often, OHCA and SCD are not nearly as sudden as the term may suggest. In many patients, warning symptoms (e.g. angina pectoris, nausea or vomiting, dyspnoea and dizziness) that precede OHCA have been present for a surprisingly long time. However, such symptoms are misinterpreted, suppressed or denied, despite the presence of pre-existing cardiac disease or its risk factors (Müller, Agrawal & Arntz, 2006). Once cardiac arrest is underway, its early recognition is critical to facilitate the prompt activation of EMS and rabid initiation of bystander-performed CPR (Perkins et al., 2015a). Conversely, if cardiac arrest is not recognised by EMS during the emergency call, then the survival rate of the patient diminishes considerably (Berdowski et al., 2009).

The wisdom that without the recognition of an event, no action will be taken in response, in the context of OHCA can amount to the difference between life or death. In short, if an OHCA emergency is not recognised, then the patient will certainly die. Accordingly, the first step in the chain of survival for OHCA involves determining whether the patient is unresponsive and whether he or she is breathing normally. Although the task sounds easy to perform, it can be challenging for bystanders and emergency medical dispatchers (EMDs)
alike, because patients experiencing cardiac arrest may exhibit agonal breathing or seizures in the first phase of the event (Travers et al., 2014, Perkins et al., 2005, Eisenberg, 2006, Dami et al., 2012, Clawson et al., 2008b). Agonal breathing can be especially misleading; although reported in 40–55% of all cases of OHCA, it can easily be interpreted as a sign of life (Clark et al., 1992, Eisenberg, 2006). Agonal breathing is abnormal, however, and thus distinguishable from other respiratory patterns (Perkin & Resnik, 2002). Nevertheless, agonal breathing persists as the chief barrier to the early recognition of cardiac arrest (Hardeland et al., 2016). In a study conducted amongst medical students, the correct identification of normal versus abnormal breathing (i.e. sensitivity) was only 60%, and specificity was observed for 75% of breathing types. Even for medical physicians, evaluating breathing can prove challenging (Smereka et al., 2016). In any case, the inability to distinguish normal from abnormal breathing can prompt a number of inappropriate actions (Perkins et al., 2005). Often the patients with OHCA who exhibit agonal breathing appear to be merely those who have the greatest potential to survive. Their OHCA should definitely be recognised (Travers et al., 2014).

Findings concerning the correct recognition of real cardiac arrests vary considerably amongst studies. The highest reported values for such sensitivity have been approximately 97% and the lowest approximately 15% (Ma et al., 2007, Heward, Damiani & Hartley-Sharpe, 2004). As mentioned, the most common symptoms used to diagnose or recognise cardiac arrest over the phone are unconsciousness and absence of breathing or presence of abnormal breathing. Although the approach for recognising agonal breathing is widely accepted and relatively straightforward, it is also challenging. In response to that challenge, targeted education, simulation practice, feedback and the introduction of an assessment protocol for EMDs to assess the presence of agonal breathing can all increase the detection of cardiac arrest over the phone (Roppolo et al., 2009, Hardeland et al., 2016, Hardeland et al., 2017). In a before-and-after trial, the ability of EMDs to recognise cardiac arrest improved from 15% to 50% after the implementation of a protocol for recognising OHCA (Heward, Damiani & Hartley-Sharpe, 2004). Other studies of the implementation of similar protocols have reported the sensitivity of cardiac arrest recognition to be approximately 65–75% (Vaillancourt et al., 2015, Viereck et al., 2017b, Vaillancourt et al., 2011).

Time elapsed in the recognition process is another significant element of the chain of survival, as the earliest recognition of cardiac arrest can allow the earliest initiation of CPR and, thus, afford a better survival rate (Sasson et al., 2010). Although delay from the beginning of the patient’s emergency call to the healthcare personnel’s recognition moment of OHCA can vary widely, median times from the call to OHCA recognition and from the call to the initiation of chest compression are approximately 1–3 min and 3–5 min, respectively (Lewis, Stubbs & Eisenberg, 2013, Travers et al., 2014, Vaillancourt et al., 2007).

As emergency medical dispatching should be as accurate as possible to ensure patient safety and optimise the use of ambulance resources, different protocols have evolved to assist call takers in assessing and prioritising emergency situations. As mentioned earlier, two of the most common concepts supporting dispatch protocols are medical priority dispatch and criteria-based dispatch. Whereas medical priority dispatch systems are the most widespread and used primarily in North America and the United Kingdom, criteria-based dispatch systems are almost exclusively used in European countries (Torlen et al., 2017, Dami et al., 2015a, Feldman et al., 2006). Regardless of the protocol used to support and assist the assessment process, the relationship of factors identified suggests that compliance with the implemented protocol is, in itself, an important factor in the accurate recognition of a patient’s condition (Heward, Damiani & Hartley-Sharpe, 2004).

Accuracy in the dispatch process at EMCCs regarding patient priority is also vital to optimising matches between patients’ medical needs and EMS resources. Conversely, inaccuracy can prompt over-triege and under-triege. Over-triege involves the immediate response and highest priority of low-acuity cases. It consumes limited resources, often increases costs and results in a shortage of ambulances for high-acuity emergencies. Over-triege can also jeopardise EMS workers and the general population, as ambulances race around potentially congested areas without affording any significant benefits to patients. Under-triege from EMCCs involves inappropriately low response to often high-acuity cases, which can place patients at risk of situations in which their medical needs remain unmet and the appropriate level of care is delayed (Dami et al., 2015a). Over-triege seems to be somewhat frequent at EMCCs, with an incidence of 28.6–78.0%, whereas
the incidence of under-triage is reported to vary from 3.5% to 35.0% (Torlen et al., 2017, Dami et al., 2015a, Feldman et al., 2006).

In summary, the correct recognition of OHCA during the emergency call constructs the basis of the chain of survival. Despite optimisation of the EMS process, challenges are evident; the current evidence shows, that education and training of EMS personnel and correct triage and prioritisation are the key features to EMS performance (Fischer et al., 2011, Langhelle et al., 2004, Pozner et al., 2004).

2.3.2 Early bystander-performed cardiopulmonary resuscitation (CPR) to buy time

A patient who receives chest compression with or without ventilation provided by someone who is not a member of an organised EMS is said to have received bystander-performed CPR (Vaillancourt et al., 2015).

Although educating the lay public in the techniques of resuscitation was first advocated by Claude S. Beck in the late 1940s, it was not until the early 1970s that large-scale advocacy of community resuscitation was pursued, namely by Mickey Eisenberg and his colleagues in Seattle (Cooper, Cooper & Cooper, 2006). In responding to OHCA, EMS systems depend on nearby individuals to initiate CPR; otherwise, CPR is initiated too late (Cummins, 1993). Thus, in the chain of survival, early bystander-performed CPR incorporates bystanders as a part of rescue teams vital to patients’ likelihood of survival. If early recognition and calls for help are made promptly, then bystander-performed CPR can be initiated rapidly. When CPR is performed before the arrival of EMS, the survival rate of the patient doubles compared to that when CPR is not performed (Hasselqvist-Ax et al., 2015). In certain circumstances, bystander-performed CPR can even improve survival rates by four- or fivefold (Sasson et al., 2010).

If able, then bystanders with CPR training should provide chest compression and ventilation to patients experiencing cardiac arrest (Perkins et al., 2015a). When a bystander has not been trained in CPR, however, then the EMD should instruct him or her to give CPR involving chest compression only, which is easier to learn as well as perform, whilst awaiting the arrival of professional help (Rea et al., 2010, Svensson et al., 2010).

EMD-assisted CPR instruction over the phone can increase the proportion of patients with OHCA who receive bystander-performed CPR and has been associated with improved survival (Viereck et al., 2017a). However, not all patients receive bystander-performed CPR, for several reasons. Amongst factors that can impede the over-the-phone instruction of CPR, as a study of cases in which patients did not receive bystander-performed CPR has revealed, instructions were not offered in 48% of cases, most often (64%) because the patient was reported to have signs of life (e.g. agonal breathing). In 31% of cases, instructions were offered but rejected, whilst in 21% of cases, they were offered and accepted, although CPR not ultimately implemented. However, among cases in which over-the-phone instruction of CPR was offered, its implementation was most often impeded by the bystander’s physical limitations (37%). Emotional distress, the transmission of disease, incompatible patient characteristics or medicolegal concerns uncommonly impeded the delivery of CPR (12%) (Hauff et al., 2003).

Anxiety and concern abound that performing CPR for patients not experiencing cardiac arrest is harmful. In a study from King County, WA, USA, of the 1,700 patients for whom CPR instructions were initiated by EMDs, 55% were experiencing cardiac arrest, 45% were not in cardiac arrest, whereas 18% were not experiencing cardiac arrest but received chest compression from bystanders nonetheless (White et al., 2010). Of the 247 patients in the last group who completed an outcome assessment, 12% experienced discomfort, and 2% sustained injuries likely or possibly caused by bystander-performed CPR; of them, only 2% suffered a fracture, and no patients suffered visceral organ injury. Compared with the possible benefits of bystander-performed CPR for patients experiencing cardiac arrest, such results support continuing EMD-assisted CPR programmes (White et al., 2010). However, patients experiencing true cardiac arrest who had received CPR for longer and extended resuscitation from medical personnel have shown an increased risk of injury, ranging from 20% to 75% (Hoke & Chamberlain, 2004, Kim et al., 2011, Miller et al., 2014, Setälä et al., 2018).
Lewis et al. have proposed performance standards for the rapid, successful recognition of cardiac arrest, and the delivery of the initial chest compression that EMS systems can adopt as metrics to measure their performance (Lewis, Stubbs & Eisenberg, 2013):

1. Recognition of cardiac arrest in 95% of cases in which the EMD has the opportunity to assess consciousness and breathing;
2. Recognition of cardiac arrest within 1 min of the start of the call;
3. Delivery of EMD-assisted CPR chest compression in 75% of cases in which the EMD has the opportunity to assess consciousness and breathing and in which bystander-performed CPR is not already in progress; and
4. Delivery of the first EMD-assisted CPR chest compression within 2 min of the start of the call.

To elucidate those standards, Lewis et al. have also articulated definitions of the recognition of cardiac arrest and dispatcher-assisted CPR chest compression (Lewis, Stubbs & Eisenberg, 2013). Recognition of cardiac arrest is said to occur when the EMD gives CPR instructions, the EMD indicates that cardiac arrest is suspected (e.g. “We need to do CPR”) and cardiac arrest dispatch protocols are implemented. Dispatcher-assisted CPR chest compression is said to have occurred when the rescuer can be heard counting individual compressions, the caller verbally confirms that chest compression is being performed and written records later clearly indicate that CPR due to EMD instructions was provided (e.g. “Dispatcher-assisted CPR in progress”).

2.3.3 Early defibrillation to restart heart

Although the frequency of shockable rhythms as the registered initial rhythm in OHCA seems to have decreased, the vast majority of eventual survivors of OHCA are patients who have continued to present VF upon the arrival of emergency personnel (Cummins, 1993, Kuisma, Repo & Alaspää, 2001). Data suggest that with each passing minute of untreated VF, the likelihood of survival is reduced by 7–10% (Cummins et al., 1991b, Hara et al., 2015). By contrast, defibrillation administered within 3–5 min of collapse can yield survival rates as high as 70% (Valenzuela et al., 2000). However, such prompt defibrillation cannot be achieved by relying solely on EMS. In response, AEDs widely disseminated throughout a community can be used to enhance efforts towards early defibrillation and increase rates of surviving cardiac arrest. Publicly accessible, on-site AEDs used by persons other than trained public safety personnel (e.g. police officers, firefighters, border guards, security officers and bystanders) are the basis of today’s AED programmes (Marenco et al., 2001, Winkle, 2010).

The diminished frequency of shockable rhythms has created some confusion about the cost-effectiveness of publicly accessible AEDs (Kuisma, Castren & Nurminen, 2003). ERC guidelines suggest implementing publicly accessible AEDs to high-density areas with an abundant movement of people, including airports, bus and ship terminals, railway stations, sports facilities and shopping malls, where OHCA is often witnessed. Although such locations are quite reasonable for AEDs, the overall frequency and location of AEDs required for sufficiently rapid response remain poorly established, especially when cost-effectiveness is taken into account. Areas where cardiac arrest is expected to occur every five years are considered to be cost-effective for the installation of AEDs and comparable to the provision of other medical interventions (Perkins et al., 2015a). If approximately 30% (~50%) of all initial rhythms are shockable, these public defibrillators would be used roughly once every 10–15 years. However, in observed OHCA occurring in public rather than at home, the rate of shockable rhythm has been reported to be even 60%, which supports the emphasis on public AED utilisation programmes (Pollack et al., 2018). In Finland, the current amount of community- or privately-maintained publicly accessible defibrillators is not known. The optional registry of these public defibrillators has been used since 2012. At present, it consists of 2,360 devices with location data (www.defi.fi), but the real quantity of devices is assumed to be clearly higher. Currently, the EMCCs in Finland do not actively utilise this AED registry data when providing telephone CPR instructions.
2.3.4 Early advanced life support and standardised post-resuscitation care

For EMS at the scene of OHCA, achieving ROSC is the first essential step of the chain of survival and the chief goal. Most often, ROSC should be achieved not at a hospital but in the field, for survival to hospital discharge after OHCA is rare when ROSC is not achieved there (Wampler et al., 2012). The response of advanced life support teams with paramedics or emergency physicians, if not both, with the capacity to supply airway management, administer medication and rectify causal factors can be necessary if initial attempts at resuscitation are unsuccessful. Even then, controversy persists about the medications and airway-management techniques to be used during resuscitation. In particular, the use of adrenalin during resuscitation has sparked debate and even criticism concerning its actual benefits (Loomba et al., 2015, Sagisaka et al., 2017, Hansen et al., 2018). Nevertheless, adrenalin is included in resuscitation guidelines and considered to be first-line medication in cases of ASY and PEA. Reports of the use of airway-management techniques involving advanced methods during resuscitation have also presented conflicting results (Hasegawa et al., 2013, McMullan et al., 2014, Hiltunen et al., 2016). In any case, once ROSC is achieved, the airway can reasonably accommodate measures taken to optimise the patient’s gas exchange, and vital body functions can thereafter be stabilised. At that point, the objectives of EMS are normal carbon dioxide and oxygen values, stable haemodynamics and, if necessary, the sedation of the patient (Wang et al., 2017, Russo et al., 2017).

Since 2005, ERC guidelines have focused on three aspects of post-resuscitation care: temperature management (i.e. therapeutic normo-/hypothermia), immediate coronary angiography with percutaneous coronary intervention when appropriate and proper prognostication before the withdrawal of care (Nielsen et al., 2013, Hypothermia after Cardiac Arrest Study Group, 2002). Currently, post-resuscitation treatment and care should be provided in centres that focus on post-arrest care and where standardised protocols involving the mentioned interventions for patients are available (Grasner et al., 2011, Elmer et al., 2016). Greater adherence to recommended hospital-based post-resuscitative care guidelines is associated with greater survival and favourable neurological status upon discharge. However, recent studies have indicated that differences in hospital care can explain many observed differences in survival after OHCA. A recent survey study in Denmark, Finland, Iceland, Norway and Sweden, for example, has even suggested worrisome variations in post-resuscitation care provided, calling for action in response in the upcoming years (Soreide & Larsen, 2015, Saarinen et al., 2015).

2.3.5 Who survives

As mentioned earlier, the current overall survival rate of patients who have experienced OHCA is roughly 10% (Grasner et al., 2016). The aim of the resuscitation chain of survival, of course, is not only survival but also the minimisation of injury and damage to the patient—that is, survival with good neurological and cerebral function. To assess neurological outcomes following cardiac arrest, Cerebral Performance Category (CPC) scores are widely used in research and quality assurance assessments (Ajam et al., 2011) (Table 5). Considered to reflect positive outcomes and independence in daily living, CPC scores of 1–2 are achieved upon hospital discharge in approximately 80% of patients (CARES Summary Report, Demographic and Survival Characteristics of OHCA, 2018).

| CPC 1 | Good cerebral function. Conscious and alert. Can work and live a normal life. Possible minor psychological or neurological defects (e.g. mild dysphasia). |
| CPC 2 | Moderate cerebral dysfunction. Conscious. Cerebral function good enough to allow part-time work in a sheltered environment, the use of public transport and the management of activities of daily living. Possible severe cerebral sequelae involving hemiplegia and dysarthria. |
| CPC 3 | Severe cerebral dysfunction. Conscious. Dependent on others at an institution or at home with exceptional support from family members or others for activities of daily living due to severe cerebral dysfunction |
| CPC 4 | Coma. No verbal or psychological communication with others. |
| CPC 5 | Braindead |

In cases of cardiac arrest, few precious minutes are available for effective resuscitation before irreversible cerebral and cardiac changes make recovery impossible (Chamberlain, 2010). Thus, the likelihood of survival following OHCA declines as the interval from collapse to treatment increases (Gold et al., 2010). In addition to prompt action, several other major clinical criteria exist to predict survival after OHCA, including witness by a bystander or EMS staff member, provision of bystander-performed CPR, shockable initial cardiac rhythm and the achievement of ROSC in the field (Sasson et al., 2010, Okubo et al., 2017).

Currently, non-shockable rhythms most often represent initial rhythms in OHCA, whereas approximately 20% of all survivors exhibited ASY or PEA as their initial rhythms (Holmgren et al., 2010). Patients whose non-shockable initial rhythms convert to shockable during the resuscitation process may have better possibilities to achieve ROSC and survival than those with non-converting shockable rhythm (Rajan et al., 2017).

On the whole, bystander-performed CPR is essential and vital important to patients’ survival and quality of life (Kragholm et al., 2017). Furthermore, by extension, high-quality bystander-performed CPR is associated with even better survival rates (Vadeboncoeur et al., 2014, Idris et al., 2015). According to guidelines, the rate of chest compressions should be 100–120 per min and the depth of compressions should be 50–60 mm, with complete recoil and minimal interruptions in the performance of CPR (Vadeboncoeur et al., 2014, Idris et al., 2015). In addition to short-time survival, bystander-performed CPR also seems to be associated with long term impact (Geri et al., 2017). The results of a study evaluating the prognostic impact of bystander-performed CPR on five-year outcomes have indicated that bystander-performed CPR has reduced hospital costs related to acute OHCA care and has been positively associated with patients’ long-term survival. According to that study’s results, of the 4,448 patients with OHCA of medical origin, 19% were discharged alive from the hospital, and 12% were still living five years later. Somewhat remarkably, the rate of five-year survival was higher for patients who had received bystander-performed CPR (14%) than for those who had not (9%). In fact, bystander-performed CPR increased the adjusted odds of survival to hospital admission by 16%, survival to hospital discharge by 26%, and five-year survival by 30% (Geri et al., 2017).

Delay between the collapse of the patient and the emergency call is also critical. If the delay is brief, then the EMS response arrives earlier, and the survival rate of the patient increases (Swor et al., 2008).

After achievement of ROSC, post resuscitation care with good quality is mandatory when striving towards the best possible survival rate (Monsieurs et al., 2015). Without it the survival of the patient cannot be optimal. However, remarkable differences may appear because doctors and institutions have different criteria for the OHCA patients’ ICU admission regardless of the international guidelines (Saarinen et al., 2015). Primary rhythm, age and performance status of the patient or timelines of resuscitation may evoke the idea of poor prognosis and prevent ICU admission, thus, leading to a self-fulfilling prophecy.

Last, it makes a significant difference if a cardiac arrest is recognised by an EMD. If arrest is not recognised, then it takes significantly longer for EMDs to dispatch an appropriate EMS response team, and they do not offer CPR instructions to bystanders over the phone, both of which significantly decrease patients’ survival rates (Berdowski et al., 2009).

In sum, continued efforts to improve the quality of the chain of survival for patients with OHCA seem to be the key to the steadily improving their rate of survival (Sporer et al., 2017).
3 AIMS OF THE STUDY

The chief aim of the research conducted for this thesis was to determine the impact of EMCC recognition of OHCA on ROSC, the survival rates of patients and the primary elements in their chain of survival with an evaluation of an OHCA registry and, in turn, assess the option of using mobile technology to enhance the recognition process.

To that end, three specific aims were adopted:

1. To evaluate the impact of EMD recognition of OHCA on the rate of ROSC, the survival rates of patients and the principal elements in their chain of survival;

2. To evaluate whether bipolar ECG signals, collected within an area the size of a mobile phone, are of sufficient quality to be automatically analysed by commercial software and to consider whether bystander-performed ECG recordings with a mobile phone could be used in the recognition process of OHCA; and

3. To evaluate whether VF, recorded within an area the size of a mobile phone, is valid for ECG rhythm analysis, and to consider whether mobile phone-based rhythm analysis can apply to OHCA recognition.
4 WITNESSED OUT-OF-HOSPITAL CARDIAC ARREST-EFFECTS OF EMERGENCY DISPATCH RECOGNITION

4.1 ABSTRACT

4.1.1 Background

Survival from an out-of-hospital cardiac arrest (OHCA) depends on the sequence of interventions in “the chain of survival”. If OHCA is recognised in the emergency medical communication centre (EMCC), the proper emergency medical service (EMS) should be dispatched and cardiopulmonary resuscitation (CPR) instructions should be given to a bystander.

The study aimed to examine the impact of OHCA recognition in the EMCC on survival rates and the main elements of the chain of survival.

4.1.2 Methods

Data from the Helsinki University Hospital’s registry of OHCA patients between 1997 and 2013 were studied. Altogether, 2054 EMCC-handled and bystander-witnessed OHCA proven events of cardiac origin were analysed.

4.1.3 Results

In 80.5% of the victims, two EMS units were correctly dispatched and the OHCA was classified as recognised. Achieved return of spontaneous circulation (ROSC) and survival to hospital discharge were 49% and 23%, respectively, if cardiac arrest was recognised by the EMCC and 40% and 16% when it was not (p=0.003 and 0.002). Dispatchers gave CPR instructions in 60% of the recognised OHCA cases. Bystander-performed CPR increased over time and was given in 58% of the recognised OHCAs and also in 17% of the unrecognised events. EMS delays were shorter if OHCA was recognised as opposed to unrecognised (8 min with an IQR 6.5–10 min versus 9 min with an IQR 6.5–11 min; p=0.001).

4.1.4 Conclusions

Recognition of OHCA by the EMCC was significantly associated with an increased rate of bystander-performed CPR, reduced EMS response time, and increased OHCA patient ROSC and survival rates.
4.2 INTRODUCTION

The overall survival rate for victims of out-of-hospital cardiac arrest (OHCA) has remained low over the last several decades (Sasson et al., 2010). However, recent reports seem to indicate a reason for some degree of optimism with respect to survival rates (Ringh et al., 2009, Wissenberg et al., 2013, Chan et al., 2014). A trend toward better survival rates for OHCA patients has been described in sites that emphasize performance improvement (Wissenberg et al., 2013, Chan et al., 2014, Ringh et al., 2015a). Despite the high total OHCA-associated mortality rate, the prognosis for ventricular fibrillation (VF) victims who receive bystander-administered cardiopulmonary resuscitation (CPR) seems to be gradually improving (Sasson et al., 2010, Ringh et al., 2015a) The survival rate of OHCA is associated with a sequence of interventions in “the chain of survival” (Frohlich et al., 2013). The term incorporates early recognition of the OHCA event, early bystander-administered CPR and defibrillation, early advanced life-support, and standard post-resuscitation care. Better survival rates appear to be the consequence of prompt recognition of the event by the emergency medical communication centre (EMCC), appropriate and rapid emergency medical service (EMS) responses, and the dispatcher’s instructions and encouragement of bystanders in performing CPR (Wissenberg et al., 2013, Rajan et al., 2016, Nichol et al., 2016). The most important factor affecting patient prognosis is the time delay from collapse to onset of resuscitation efforts. Each passing minute of untreated ventricular fibrillation (VF) reduces the likelihood of survival by 3% to 7% (Gold et al., 2010, Waalewijn et al., 2001).

In an out-of-hospital setting, a bystander who recognises the collapse can call the EMCC. When following the standardised protocol, the emergency medical dispatcher’s (EMD) ability to remotely recognise cardiac arrest varies from one region to another but is reported to be on the average of 70% (Viereck et al., 2017b). When an EMD accurately recognises cardiac arrest, the pathway to possible survival can be established. OHCA recognition by the EMCC is a crucial point for the cardiac arrest victim’s chain of survival. This study aimed to describe the impact of EMCC recognition of OHCA on return of spontaneous circulation, the survival rates of patients and principal elements of the chain of survival.

4.3 METHODS

4.3.1 Ethics and subjects

This registry study was approved on 23.05.2014 by the Hospital District of Helsinki University Hospital according to Finnish legislation for medical research (identification number 103/2014). The study is a retrospective registry survey, but data were collected prospectively. OHCA events were retrieved from the Helsinki University Hospital’s registry of OHCA patients documented from 1997 to 2013 for examination. This registry, maintained by emergency physicians, contains structured data of all the OHCA events in Helsinki City. A more detailed description of this registry has been published previously (Kuisma et al., 2005).

OHCA victims were included in the study if:

1. The case record in the registry clearly stated whether or not EMCC recognised the case as an OHCA;
2. patient’s age was above 18 years;
3. a bystander witnessed the OHCA from the onset;
4. an emergency physician defined the arrest as most probably of cardiac origin.

The exclusion criteria included events in which resuscitation was not attempted, and the OHCA was either not witnessed or was witnessed by the EMS (Figure 2).
4.3.2 The EMS dispatching regimen in Helsinki, Finland

The Finnish EMS consists of three tiers: 1) emergency medical technicians (EMTs); 2) paramedics; and 3) emergency physician-staffed mobile intensive care units (Figure 2).

Despite the reformation of the organisation of the EMCCs in Finland during the study period, the area of Helsinki City was constantly served by a one determined EMCC department. An emergency phone call is received by the EMCC per a uniform protocol. Emergency calls are categorised from A to D according to the urgency of the event. Category A represents the most urgent and includes OHCA s. OHCA identification is based on determination of the victim’s consciousness and breathing pattern. If the dispatcher concludes that the event is an OHCA, two EMS units are sent to the scene. The first one, an EMT or paramedic unit, is dispatched in the early phase of the emergency call, and the second, a paramedic or an emergency physician unit, is dispatched when the event’s high priority and necessity for two EMS units is confirmed. If CPR is not currently being attempted, the dispatcher provides CPR instructions by phone (protocol since 01.03.1998). More detailed descriptions of the EMS dispatching regimens can be found in an earlier publication (Kuisma et al., 2005).

4.3.3 Study design

In this study, patients were grouped according whether the OHCA was correctly recognised by the EMCC. An accurate recognition of an OHCA was defined by the implementation of the standard OHCA dispatch protocol and dispatch of two EMS units to the scene, including both the nearest EMS unit and either the emergency physician on duty or the field supervisor paramedic. In contrast, cases in which the first EMS unit assessed the situation as an OHCA on arrival and called to a second EMS unit for assistance was registered as failure to recognise the case as an OHCA.

The primary outcomes were defined as return of spontaneous circulation, survival until hospital discharge and the one-year patient survival rates based on whether the all-rhythm OHCA was EMCC-recognised or not. With regard to secondary outcomes, the impact of the OHCA recognition on the principal elements in the chain of survival and on the survival rate were examined. These elements were defined according to several parameters: 1) dispatchers’ successful telephone CPR instructions; 2) bystander-administered CPR rate; 3) EMS response time; 4) patient’s initial rhythm (shockable versus non-shockable); 5) any (≥30 seconds) return of spontaneous circulation on the field (ROSC); and 6) patient survival rates in the shockable and non-shockable subgroups.


4.3.4 Data analysis

The data were analyzed using IBM SPSS statistics software version 23 and were presented as frequencies and percentages. For normally distributed continuous variables, means and standard deviations (SD) are presented, and an independent samples T-test was used to test significance. All categorical variables were analysed using the chi-square test or Fischer’s exact test. Median and interquartile ranges (IQR) are presented for non-normally distributed data, and the Mann–Whitney U Test or Kruskal–Wallis Test was used to test significance. All significance tests were two-tailed with p ≤0.05 considered statistically significant.
4.4 RESULTS

4.4.1 Patients

A total of 6105 OHCA patients were registered between 1997 and 2013. According to our criteria, 2054 patients were included in the analysis. Patients’ characteristics are described in Figure 2.

Figure 2. The Utstein OHCA template. The available core information described with the Utstein OHCA template. The reported values are from the patients included in the study (in bold). Response time is the median time delay from the emergency call to the EMS unit arrival beside the patient at the scene. OHCA, out-of-hospital cardiac arrest; EMS, emergency medical service; CPR, cardio pulmonary resuscitation; ROSC, return of spontaneous circulation; CPC, cerebral performance category.
4.4.2 OHCA recognition, achieved ROSC and survival rate

The EMCC recognised OHCA in 80.5% of the events during the study period, and ROSC was achieved in 47% of all the studied patients. The overall survival rate of patients to hospital discharge was 22%. If the OHCA was recognised by the EMCC, the achieved ROSC and the hospital discharge rates were 49% and 23% versus 40% and 16% in the unrecognised patient group (p = 0.003, odds ratio [OR] 1.40; 95% confidence interval [CI] 1.12–1.75 and p = 0.002, OR 1.56; 95% CI 1.17–2.08, respectively). The overall one-year survival rate was 19%; 20% in the recognised OHCA group versus 13% in the unrecognised group (p = 0.003, OR 1.66; 95% CI 1.21–2.26) (Table 6).

Table 6. Characteristics of the patients and the main elements of the chain of survival. The number of the events, where the essential data, whether the out-of-hospital cardiac arrest (OHCA) was recognized or unrecognized by the dispatcher, was 2054. The rest of the parameters were calculated according to the number of available data among these 2054 events. EMS, emergency medical service; CPR, cardio pulmonary resuscitation; ROSC, return of spontaneous circulation; IQR, inter quartile range; OR, odds ratio; CI, confidence interval; n, number; ns, non-significant; * n/available data.

<table>
<thead>
<tr>
<th></th>
<th>All OHCA events</th>
<th>Recognised events</th>
<th>Unrecognised events</th>
<th>Available data</th>
<th>P value (OR and 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%)</td>
<td>2054</td>
<td>1653 (80.5)</td>
<td>401 (19.5)</td>
<td>2054</td>
<td>ns</td>
</tr>
<tr>
<td>Age years median, (IQR)</td>
<td>67 (57–77)</td>
<td>67 (57–77)</td>
<td>68 (58–77)</td>
<td>2054</td>
<td>ns</td>
</tr>
<tr>
<td>Age group &lt;50 n (%)</td>
<td>221</td>
<td>184 (83)</td>
<td>2054</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>50 -70 n (%)</td>
<td>941</td>
<td>756 (80)</td>
<td>2054</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>≥70 n (%)</td>
<td>892</td>
<td>713 (80)</td>
<td>2054</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Male (%)</td>
<td>72</td>
<td>73</td>
<td>71</td>
<td>2054</td>
<td>ns</td>
</tr>
<tr>
<td>EMS response time minutes (IQR)</td>
<td>8 (6.5–10)</td>
<td>8 (6.5–10)</td>
<td>9 (6.5–11)</td>
<td>2043</td>
<td>0.001</td>
</tr>
<tr>
<td>Shockable rhythm, n (%)</td>
<td>1048 (51)</td>
<td>891/1648* (54)</td>
<td>157/401* (39)</td>
<td>2049</td>
<td>&lt;0.001 (1.83; 1.46–2.29)</td>
</tr>
<tr>
<td>CPR instructions, n (%)</td>
<td>934 (49)</td>
<td>909/1519* (60)</td>
<td>25/364* (7)</td>
<td>1903</td>
<td>&lt;0.001 (21.40: 14.09–32.51)</td>
</tr>
<tr>
<td>Bystander CPR, n (%)</td>
<td>1017 (50)</td>
<td>950/1638* (58)</td>
<td>67/398* (17)</td>
<td>2036</td>
<td>&lt;0.001 (6.82; 5.15–9.03)</td>
</tr>
<tr>
<td>ROSC, n (%)</td>
<td>968 (47)</td>
<td>806/1653* (49)</td>
<td>162/401* (40)</td>
<td>2054</td>
<td>0.003 (1.40; 1.12–1.75)</td>
</tr>
<tr>
<td>Hospital discharge, n (%)</td>
<td>448 (22)</td>
<td>383/1653* (23)</td>
<td>65/401* (16)</td>
<td>2054</td>
<td>0.002 (1.56; 1.17–2.08)</td>
</tr>
<tr>
<td>Survival 1 year, n (%)</td>
<td>391 (19)</td>
<td>337/1644* (20)</td>
<td>54/401* (13)</td>
<td>2045</td>
<td>0.001 (1.66; 1.21–2.26)</td>
</tr>
</tbody>
</table>

4.4.3 Survival according to the initial rhythm

The initial rhythm of the patients was shockable in 51% of cases. In the group where the OHCA was recognised by the EMCC, the rhythm was shockable in 54% of victims; if unrecognised, it was shockable in 39% (p = 0.001, OR 1.83, 95% CI 1.46–2.29). In shockable rhythms, ROSC/hospital discharge/one-year survival rates were 64% /39%/ 34% and in non-shockable rhythms 27%/4.2%/3.4% (Tables 6 and 7).

Survival to hospital discharge from shockable rhythms, without recognition of OHCA and without bystander initiated CPR, was 27%. If the OHCA was recognised and bystander-administered CPR was achieved, the survival rate was 46% (p <0.001; OR 2.29, 95% CI 1.46–3.60) (Figure 3).
Table 7. The characteristics of patients and the main elements of the chain of survival according to the initial rhythm. The variables were calculated by the number of available data among the 2054 studied events. EMS, emergency medical service; CPR, cardio pulmonary resuscitation; ROSC, return of spontaneous ventilation; IQR, inter quartile range; OR, odds ratio; CI, confidence interval; n, number.

<table>
<thead>
<tr>
<th>Initial rhythm</th>
<th>Shockable rhythm (n=1048)</th>
<th>Not shockable rhythm (n=1001)</th>
<th>P value (OR and 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part of recognized OHCA (%)</td>
<td>891/1648 (54)</td>
<td>757/1648 (46)</td>
<td>&lt;0.001 (1.83; 1.46-2.29)</td>
</tr>
<tr>
<td>Part of not recognized OHCA (%)</td>
<td>157/401 (39)</td>
<td>244/401(61)</td>
<td>&lt;0.001 (0.55; 0.44-0.68)</td>
</tr>
<tr>
<td>Age years (IQR)</td>
<td>65 (56-73)</td>
<td>70 (59-79)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male (%)</td>
<td>826/1048 (79)</td>
<td>653/1001 (65)</td>
<td>&lt;0.001 (1.98; 1.63-2.42)</td>
</tr>
<tr>
<td>EMS response time minutes (IQR)</td>
<td>8 (6-10)</td>
<td>9 (7-11)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CPR instructions (%)</td>
<td>618/1036 (60)</td>
<td>394/995 (40)</td>
<td>&lt;0.001 (2.26; 1.89-2.70)</td>
</tr>
<tr>
<td>Bystander CPR (%)</td>
<td>674/1048 (64)</td>
<td>291/1001 (29)</td>
<td>&lt;0.001 (4.39; 3.64-5.29)</td>
</tr>
<tr>
<td>ROSC (%)</td>
<td>405/1048 (39)</td>
<td>42/1001 (4.2)</td>
<td>&lt;0.001 (14.38; 10.32-20.07)</td>
</tr>
<tr>
<td>Hospital discharge (%)</td>
<td>356/1041 (34)</td>
<td>34/999 (3.4)</td>
<td>&lt;0.001 (14.75; 10.24-21.25)</td>
</tr>
<tr>
<td>Survival 1 year (%)</td>
<td>356/1041 (34)</td>
<td>34/999 (3.4)</td>
<td>&lt;0.001 (14.75; 10.24-21.25)</td>
</tr>
</tbody>
</table>

Figure 3. Shockable rhythm and hospital discharge. The impact of recognition of out-of-hospital cardiac arrest and bystander-performed cardio-pulmonary resuscitation (CPR) on hospital discharge when the initial rhythm was shockable (P < 0.001).

4.4.4 Rate of telephone CPR instructions and bystander CPR

Dispatchers provided bystanders with CPR instructions by phone in 60% of recognised OHCA events. In 77% of the events in which instructions were provided, bystander CPR was performed. Altogether bystander CPR was performed in 58% of EMCC-recognised OHCA and in 17% of unrecognised events (Table 6).

4.4.5 EMS response time

The median time delay from the emergency call until the EMS unit arrival beside the patient at the scene was 8 (6.5–10) min. If the OHCA event was recognised by the EMCC, the delay was 8 (6.5–10) min; if unrecognised, it was 9 (6.5–11) min (p= 0.001) (Table 6).
4.4.6 Impact of the revised guidelines

The recognition of OHCA improved over time. From 1997 to 2000, EMCC recognition of OHCA events was 74%, and during the final years of the study (2011–2013), it was 82% (p <0.001) (Table 8).

Over time, the survival rate of all-rhythm OHCA patients for hospital discharge fluctuated from a minimum of 18% (2001–2005) to a maximum of 28% (2005–2010) during the follow-up period (p= 0.001) (Table 8).

In the subgroup of shockable rhythm, a trend toward better survival rates over time was seen for hospital discharge from 34% to 41-46% (Figure 4). Survival rates at one year post-event followed a similar trend.

The telephone CPR instruction rate also increased over time. From 1997 to 2000, instructions were given in 28% of OHCA events and 76% of these events from 2011 to 2013 (Table 8). The rate of bystander-administered CPR increased from 31% to 63% over the study period (Table 8). The average trend in response times seemed to increase over time (Table 8).

Table 8. The trends of parameters per the release dates of the revised American Heart Association /European Resuscitation Council CPR guidelines. The variables were calculated by the number of available data among the 2054 studied events. EMS, emergency medical service; CPR, cardio pulmonary resuscitation; ROSC, return of spontaneous circulation; IQR, inter quartile range; n, number.

<table>
<thead>
<tr>
<th>All rhythm OHCA</th>
<th>1997-2000 n=525</th>
<th>2001-2005 n=649</th>
<th>2006-2010 n=529</th>
<th>2011-2013 n=351</th>
<th>P value between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognized n (%)</td>
<td>391 (74)</td>
<td>519 (80)</td>
<td>454 (66)</td>
<td>289 (82)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EMS response time minutes (IQR)</td>
<td>8 (6-10) (522)</td>
<td>8 (6.5-10) (643)</td>
<td>8 (6-10) (527)</td>
<td>9 (7-10) (351)</td>
<td>0.003</td>
</tr>
<tr>
<td>Shockable rhythm, (%)</td>
<td>267/525 (51)</td>
<td>308/648 (48)</td>
<td>305/529 (58)</td>
<td>168/347 (48)</td>
<td>0.004</td>
</tr>
<tr>
<td>CPR instructions, (%)</td>
<td>137/495 (28)</td>
<td>259/620 (42)</td>
<td>290/461 (63)</td>
<td>248/327 (76)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bystander CPR, (%)</td>
<td>162/519 (31)</td>
<td>309/639 (48)</td>
<td>324/527 (61)</td>
<td>222/351 (63)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ROSC (%)</td>
<td>260/525 (50)</td>
<td>290/648 (45)</td>
<td>264/529 (50)</td>
<td>153/351 (44)</td>
<td>0.108</td>
</tr>
<tr>
<td>Hospital discharge, (%)</td>
<td>108/525 (21)</td>
<td>119/649 (18)</td>
<td>146/529 (28)</td>
<td>75/351 (21)</td>
<td>0.001</td>
</tr>
<tr>
<td>Survival 1 year, (%)</td>
<td>88/523 (17)</td>
<td>107/647 (16)</td>
<td>126/525 (24)</td>
<td>70/350 (20)</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Figure 4. Trend of initial rhythm as shockable and the main elements of the chain of survival. Initial rhythm as shockable, dispatcher recognized out-of-hospital cardiac arrest, dispatcher was giving cardio pulmonary resuscitation (CPR) instructions, bystander-performed CPR, and hospital discharge over time. The time series are per the release dates of the revised American Heart Association/European Resuscitation Council CPR guidelines. P values are between the groups.
4.5 DISCUSSION

In this study the EMCC-recognised OHCA improved the OHCA victims’ ROSC and survival rates. The rate of achieved ROSC, reflecting the performance of the EMS system without in-hospital care influence, and patient survival until hospital discharge were 49% and 23%, respectively, when OHCA was recognised versus 40% and 16% when it was not. The relative improvements were 23% and 44%, respectively. This supports previous findings and emphasizes the critical lifesaving role of dispatchers as part of the EMS system (Berdowski et al., 2009, Lerner et al., 2012).

The role of dispatcher in the EMCC is to assess the priority of the emergency event, initiate immediate first aid for the victim from bystanders, and reasonably allocate any available, often limited, EMS resources (Ornato, 2009, Palumbo et al., 1996). With prompt recognition of an OHCA the dispatcher has the opportunity to enhance the victim’s survival (Rea et al., 2001, Bohm et al., 2009, Roppolo et al., 2009). In this study, the proportion of EMCC-recognised OHCAs has improved over time from 74% to 82%. This strengthens the first link in the chain of survival; nevertheless, there is still room for improvement. In a recent report from Norway the already high OHCA recognition sensitivity improved to 95% with additional targeted interventions (Hardeland et al., 2017). However, the reported OHCA recognition sensitivity varies widely among EMCCs (average of 70%) (Vaillancourt et al., 2011). The recognition rate is not the only important factor; the time frame in which it occurs and the actions it generates are also crucial (Lewis, Stubbs & Eisenberg, 2013).

Currently, OHCA recognition by the EMCC is based on questions regarding the victim’s consciousness and breathing patterns. Most often, the recognition process categorizes the event as lack of consciousness or cardiac arrest; both have high priority, yet with the latter requiring the most immediate action. Though unconsciousness with reported abnormal breathing can be anticipated as CA, the matter is not so straightforward. Repeatedly, dispatchers must determine whether the patient is breathing or not. The evaluation of breathing is challenging for lay people, and the OHCA event may be confused with agonal breaths or convulsions (Bang, Herlitz & Martinell, 2003). Furthermore, OHCA victims with confusing agonal breaths are actually those who may have the greatest potential to survive cardiac arrest (Travers et al., 2014). Their cardiac arrest may remain unrecognised by the EMCC since it may appear they are breathing.

In this study, the OHCA registry data did not include the time delay from the beginning of the emergency call to the moment the dispatcher recognised the OHCA. The OHCA was recognised and defined as such if the appropriate emergency code utilised for the emergency team was recorded as cardiac arrest before the team arrived at the scene; hence, the time frame to the recognition of OHCA was variable ranging from the first moments of the emergency call to just before the dispatched units reached the patient. In other studies, the average time delay from the beginning of the emergency call to the recognition of arrest was reported to be 1:15–3:39 min (Lewis, Stubbs & Eisenberg, 2013, Travers et al., 2014, Clegg et al., 2014). Even for the most competent dispatchers, there are invariably OHCA events among the emergency calls that are not recognised by the EMCC for various reasons (Alfsen et al., 2015).

Recognition of an OHCA should result in appropriate dispatching of EMS units to the scene to ensure effective and competent advanced life support. In this study, EMS delays were shorter if OHCA was recognised versus those not recognised (8 [6.5–10] min versus 9 [6.5–11] min). In the unrecognised cases, the EMS team reached the patient later and had incomplete resources. Overall, the EMS delay time seemed to increase over the study period and has also been reported in other studies. Increasingly burdened EMS units, increasing traffic density in urban areas, and an increasing responsibility on EMS units due to new tasks may explain this trend (Stromsoe et al., 2015, Nehme, Andrew & Smith, 2016).

When an OHCA is recognised, the dispatcher should encourage and instruct the bystander on how to start and perform CPR. In this study, OHCA recognition resulted in CPR instructions in 60% of the cases in which CPR had not already been attempted, and bystander CPR was performed in 58% of the recognised events. These numbers are averages from the whole study period and show an increasing trend over time. They are lower than in a recent report from Denmark, however, in which CPR instructions were given in 97.5% of OHCA events and bystander CPR was achieved in 73.3% of the patients (Viereck et al., 2017a). In this study, the reasons why dispatchers did not give CPR instructions or bystanders did not perform CPR, were not available from the OHCA registry.
The frequency with which dispatchers gave telephone CPR instructions and the bystanders’ rates of administering CPR appear to be influenced by the frequently revised and implemented AHA/ERC CPR instructions, which emphasize that the lay rescuer provide chest compressions. For certain segments of bystanders there are inevitably various mental or physical barriers that prevent them from performing CPR even if dispatchers provide CPR instructions. However, it is possible that in some cases, a number of such barriers could be surmounted with more encouragement from the dispatcher (Alfsen et al., 2015, Bobrow, Panczyk & Subido, 2012). The obligation to act without facing any adverse legal reactions and confidence between community citizens and social institutions seem to also be important factors behind CPR provision (Mathiesen et al., 2017).

It is well documented that the vast majority of all OHCA survivors presented with a shockable rhythm when the EMS team first examined the victim at the scene (Hara et al., 2015). In this study, ROSC was achieved in 64% of the patients, and the survival-to-hospital discharge rate was 39% if the initial rhythm was shockable versus 29% and 4% if it was not. Over time, the rate to hospital discharge for patients with shockable initial rhythms improved from 34% to 41%–46%. The significance of OHCA recognition and bystander-administered CPR was clear; although the hospital discharge rate was 27% for patients with an unrecognised shockable rhythm, 46% of patients with witnessed OHCA, recognised by the EMCC and given bystander CPR survived until hospital discharge.

The portion of VF as the initial rhythm in OHCA events has been decreasing in number (Hulleman et al., 2015, Herlitz et al., 2004). Compared to recently published studies, in this study, shockable rhythm was frequently presented (Grasner et al., 2016). Usually, VF arrest is the consequence of myocardial ischemia. Here, only the OHCA events that were regarded as most probably of cardiac origin were included in the analysis, which may partly explain the high proportion of VF. In addition, OHCA recognition sensitivity in the EMCC was relatively high and associated with a shockable presenting rhythm. OHCA recognition led dispatchers to give CPR instructions by phone to bystanders, and bystander CPR was attempted in almost 60% of the events. This action probably maintained the primary rhythm as shockable. Additionally, the recognition of OHCA led to faster EMS response times compared with unrecognised OHCA events, which enabled the EMS team to discover a shockable rhythm. Even though shockable rhythm was associated with the recognition of the arrest and achieved ROSC, the relative proportion of ROSC did not increase over the study period.

There are several limitations to this study. First of all, the analysed OHCA events were bystander-witnessed OHCAs of cardiac origin from an urban area where an emergency physician also is involved in the treatment of the patients; hence the outcome results must be interpreted in this context. In this study there was no automatic registry data collection; thus, frequently, the accuracy of the collected data was dependent on the exactness of intermediaries. During the period studied, improvements in resuscitation care have been implemented in practice. Using the available data, it was not possible to determine the extent to which these therapeutic interventions influenced outcomes. However, the survival to discharge following OHCA recognition and bystander-attempted CPR was significantly better than the survival rate in the unrecognised patient group (p <0.001, OR2.39; CI 1.69–3.39) even during the years 2006–2013 after implementation of therapeutic hypothermia. The decision about whether the CA of the patients who died out of hospital were of cardiac origin was most often based on the judgement of the physician involved in the case and not on an autopsy. Our analyses were not adjusted, which can be seen as a limitation. However the core measures of the study (recognition-instructions-CPR-shockable rhythm-survival) per se are a continuum rather than independent variables for multivariate analysis.

4.6 CONCLUSIONS

The recognition of OHCA in the EMCC is vital in the chain of survival for OHCA patients. Recognition of arrest by the EMCC was significantly associated with reduced EMS response time, increased bystander rates of CPR administration, increased achieved ROSC rates, and increased OHCA victims’ survival rates. Therefore, efforts to strengthen this initial step in the survival process for the OHCA victims are appropriate.
5 THE FEASIBILITY OF RECOGNISING THE HEART RHYTHM WITH AN AUTOMATED EXTERNAL DEFIBRILLATOR FROM AN AREA THE SIZE OF A MOBILE PHONE.

5.1 ABSTRACT

5.1.1 Objective

Recognition of cardiac arrest (CA) during an emergency call leans on questions concerning CA symptoms and is correct in 50–83% of cases. If the heart rhythm could be recorded and analysed over a mobile phone or transmitted during the emergency call to the dispatch centre and analysed there, using software identical to one in an automated external defibrillator (AED), CA recognition could be more prompt. We investigated whether an AED can correctly analyse normal heart rhythms recorded within an area the size of a mobile phone.

5.1.2 Methods

Bipolar ECG signal was recorded using an AED in 20 healthy volunteers in four different positions during rest and muscle tension with small pads in an area the size of a mobile phone. Recordings obtained with standard pads in standard positions served as the reference. The recorded ECGs were analysed with an AED and by two cardiologists and categorised as shockable or non-shockable.

5.1.3 Results

All analyses were correct when the recordings were performed vertically at the midsternum level. Horizontally at this level, the AED made correct analyses in 95% and 65% and the cardiologists in 100% and 88% of cases at rest or during muscle tension, respectively. In the lateral positions only the analyses by cardiologists partly reached 100% sensitivity. The analysis time of the AED was 7 s in all positions.

5.1.4 Conclusions

ECGs can be analysed promptly with an AED within an area the size of a mobile phone. The most reliable recording position was vertical at the midsternum level.
5.2 INTRODUCTION

In nonhospital settings, a bystander who recognises a possible out-of-hospital cardiac arrest (OHCA) and makes an emergency call to the emergency medical communication centre (EMCC) is the starting point of the “chain of survival” (Cummins et al., 1991b). To recognise an OHCA over the telephone, most emergency medical dispatchers (EMDs) ask a number of standardised questions. OHCA recognition, using this method, is based on questions about whether the victim is conscious or not and on the absence of breathing or the presence of abnormal breathing. With this symptom-based strategy, the EMD’s ability to recognise cardiac arrest over the telephone ranges from 50% to 83% (Heward, Damiani & Hartley-Sharpe, 2004, Garza et al., 2003, Nurmi et al., 2006).

If the EMD identifies an OHCA during the emergency call, the survival of the patient improves (Berdowski et al., 2009, Kuisma et al., 2005). The bystander will receive cardiopulmonary resuscitation (CPR) instructions and the correct emergency medical service response is promptly activated. It has been estimated that the proper implementation of CPR instructions saves thousands of lives each year (Rea et al., 2001).

When cardiac arrest occurs in an out-of-hospital setting, the emergency call is often made with a mobile phone (Gossage et al., 2008). Mobile computing technology has progressed rapidly in the previous years, and applications to record and transmit physiological data, including ECGs, with a mobile phone are technically feasible (Wong, 2013, Lyon et al., 2013). If a bipolar ECG, reflecting the heart rhythm of the possible OHCA patient, could be recorded during the call with mobile telephone-integrated electrodes and analysed using the software of an automated external defibrillator (AED; in a telephone or in the EMCC), the recognition of OHCA in EMCC could be faster and more accurate. The aim of this study was to examine whether it is possible to collect bipolar ECG signal, without any major artefacts, within an area the size of a mobile phone and analyse it correctly using the software of an AED.

5.3 METHODS

5.3.1 Participants

After approval by the Ethics Committee of Kuopio University Hospital, Kuopio, Finland (number 91//2012) we recruited 20 healthy volunteers (ten women and ten men) from among the personnel of the ICU of Kuopio University Hospital.

5.3.2 Study design

At the beginning of the study, the height and weight of each volunteer were recorded. The abundance of hair (hairiness) on the chest was graded on a scale from 0 (no hair) to 3 (very hairy). After palpation of the jugular notch and the tip of the xiphoid process, the length of the sternum was measured. The midpoint at the midline of the sternum was defined as the mid-sternal point. The circumference of the thorax was measured at the level of the mid-sternal point.

After the anatomical measurements, the volunteers lay in a supine position on a hospital bed and a test recording with standard defibrillation pads (CPR Stat-Pads; Zoll, Chelmsford, USA) was performed. Thereafter, a total of 10 bipolar heart rhythm recordings per volunteer were collected and analysed with an AED (ZOLL R-series ALS; Zoll). The first two rhythm recordings of each volunteer served as references. They were carried out with the standard AED pads, positioned according to the guidelines of the European Resuscitation Council (Fig. 5) (Koster et al., 2010). The first electrode pad was placed just below the right collar bone (sternum electrode) and the second pad in the mid-axillary line, just below the left armpit (apical electrode).

The later recordings were made with minimal-size (3 cm × 3 cm, 3 cm between pads) pads cut from the standard pads to fit within an area the average size of a standard mobile phone. The pads were trimmed to just outside the wiring zone, so that the wiring remained intact and usable for the recordings. These small
pads, not containing adhesive material, were pressed gently to the chest of the volunteer with a mobile phone (Nokia C5, Espoo, Finland) that had been switched off. A 4 kg weight was placed on the mobile phone to standardise the pressure against the pads. Recordings with the minimal-size pads were performed in four different positions on the chests of the volunteers. These positions were (I) midsternal vertical, (II) midsternal horizontal, (III) 5 cm to the left of the midsternal point (lateral point) vertical, and (IV) 5 cm to the left of the midsternal point horizontal (Fig. 5). All of the recordings were performed in the resting state and during tension of the pectoral muscles. In the tension state, the arms of the volunteers were extended to both sides of the body with the palms at the horizontal navel line. Tension of the pectoral muscles was generated by raising the extended arms up to a height of 30 cm with 3 kg weights in both hands. This tension simulated the possible, although rare, convulsions or other possible muscle tension, for example, gasping, that may occur in patients with cardiac arrest and could generate artefacts in the ECG signal (Clawson et al., 2008b, Bobrow et al., 2008).

The pads were replaced after every recording to ensure that they were functioning properly. In the recordings, the AED amplified the ECG signal with a multiplier of 1.5. All of the recordings were printed for later analysis.

Figure 5. ECG recording positions. (I) midsternal vertical, (II) midsternal horizontal, (III) 5 cm left of the midsternal point vertical, and (IV) 5 cm to left of the midsternal point horizontal. Standard AED pads were positioned according to the guidelines of the European Resuscitation Council.

5.3.3 Measurements

The amplitude of the QRS configuration was measured manually in the heart rhythm prints in millimetres. The time that the AED took for rhythm analysis was measured manually using a chronometer. The chronometer was started when the pads were put in place and the rhythm analysis of the AED was switched on, and it was stopped when the AED announced the recommendation to defibrillate or not. These results are reported as mean ± SD.

The sensitivity of the AED was defined as the correct analysis of the rhythm – that is, “defibrillation is not recommended” – for all of the recordings that were made with pads in different positions. Results are reported in percentiles.

Two experienced cardiologists assessed the rhythm prints, offering their opinion on whether the rhythms in the recorded prints were shockable or not. The cardiologists were blinded, such that they were unaware that every heart rhythm print had a regular sinus rhythm from a healthy volunteer. The cardiologists also assessed the quality of the recordings. The assessment was not standardised but was based on the opinion of very experienced clinicians. After instructions on the assessment procedure, they graded each recording according to three categories of quality: 1, poor (major artefacts; difficult or impossible to identify either QRS
configuration, nor could be judged as ventricular fibrillation (VF)/ventricular tachycardia (VT)); 2, average (artefacts but QRS configuration/VF/VT easy to identify); 3, good (no or only minor artefacts and good QRS/VF/VT configuration) (Fig. 6).

The quality grades from specific positions and states are reported as median and interquartile range (IQR). In the four lateral positions, recordings from only 19 volunteers were available to be analysed by the cardiologists, because the AED could not find any recordable signal in one of the female volunteers in these positions.

5.3.4 Data analysis

The mean and SD or the median and IQRs (quality scores) were calculated. Because this study is principally descriptive, we did not use any statistical methods to analyse the significance of the results.

5.4 RESULTS

The characteristics of the volunteers are described in Table 9.

Table 9. Volunteer characteristics. Hairiness was graded from 0 (no hair) to 3 (very hairy). BMI, body mass index.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, y</th>
<th>Weight, kg</th>
<th>Height, m</th>
<th>BMI</th>
<th>Thorax circumference, cm</th>
<th>Sternal length, cm</th>
<th>Hairiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>39.6 ± 8.8</td>
<td>76.3 ± 14.1</td>
<td>1.74 ± 0.09</td>
<td>25.0 ± 2.9</td>
<td>98.7 ± 8.0</td>
<td>21.9 ± 2.2</td>
<td>1.0 ± 1.1</td>
</tr>
<tr>
<td>Women</td>
<td>39.7 ± 7.9</td>
<td>68.0 ± 6.6</td>
<td>1.66 ± 0.04</td>
<td>24.7 ± 2.8</td>
<td>94.7 ± 5.1</td>
<td>20.6 ± 1.0</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Men</td>
<td>39.5 ± 10.0</td>
<td>84.7 ± 14.9</td>
<td>1.82 ± 0.07</td>
<td>25.4 ± 3.0</td>
<td>102.6 ± 8.7</td>
<td>23.2 ± 2.4</td>
<td>1.9 ± 0.9</td>
</tr>
</tbody>
</table>

5.4.1 Sensitivity of the ECG analysis

In this study, the most reliable bipolar ECG recording area was found to be the vertical midsternum position. All of the analyses by the AED and by the cardiologists were correct in this position (Table 10). The most unreliable recording position was the horizontal midsternum setup. In this position, the AED carried out correct analyses in 19/20 (95%) volunteers at rest, but only 13/20 (65%) volunteers during muscle tension, as compared with correct analyses of 20/20 (100%) volunteers by the cardiologists during rest and 17/20 (85%) during muscle tension (Table 10). In the female subgroup, during tension, the AED was able to analyse the ECG rhythm correctly in only 50% of the cases in this position. In the muscle-tension state, there was so much noise in the recordings that the AED incorrectly analysed even one of the reference recordings performed with the original pads. In the lateral vertical arrangement of the electrodes, the AED correctly analysed 19/20 (95%) and 17/20 (85%) heart rhythms during the resting and muscle-tension states, respectively. The AED could not find the heart rhythm signal in the lateral positions, to any extent, in one of the female volunteers; this was interpreted as an incorrect analysis. This phenomenon was also seen in the lateral horizontal arrangement, during both the resting and the tension states, and yielded the only incorrect analysis in this setting. The missing rhythm signal from the female volunteer was also the reason why the cardiologists analysed only 19 ECG prints (instead of 20) from the lateral positions. Incorrect analyses by the cardiologists occurred once for cardiologist 1 and twice for cardiologist 2, during the tension state in the lateral vertical position (Table 10). All of the incorrect analyses by the cardiologists were also analysed erroneously by the AED.
Table 10. Measurements from the ECG recordings. QRS size was measured from the ECG prints in millimetres. Analysis time refers to the time it took the AED to determine whether the rhythm was shockable or not. Sensitivity is defined as correct analyses in specific positions and states. Results are reported as mean and SD or median and interquartile range. Percentages are reported in parentheses. MS, minimal-size ECG pads within an area the size of a mobile phone.

<table>
<thead>
<tr>
<th>Electrode position</th>
<th>State</th>
<th>QRS size, mm</th>
<th>Analysis time, s</th>
<th>Sensitivity of the AED</th>
<th>Sensitivity of cardiologists</th>
<th>Quality assessed by cardiologists</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original reference pads</td>
<td>Rest</td>
<td>22.6 ± 7.4</td>
<td>7.0 ± 0.4</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>3 (3-3)</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>23.5 ± 6.9</td>
<td>6.9 ± 0.3</td>
<td>19/20 (95)</td>
<td>20/20 (100)</td>
<td>2 (2-1)</td>
</tr>
<tr>
<td>MS pads sternum vertical</td>
<td>Rest</td>
<td>12.1 ± 4.5</td>
<td>7.0 ± 0.3</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>3 (3-3)</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>12.0 ± 4.1</td>
<td>6.9 ± 0.3</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>2 (3-2)</td>
</tr>
<tr>
<td>MS pads sternum horizontal</td>
<td>Rest</td>
<td>8.9 ± 4.1</td>
<td>7.0 ± 0.7</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>3 (3-2)</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>9.9 ± 4.1</td>
<td>7.3 ± 0.9</td>
<td>13/20 (65)</td>
<td>17/20 (85)</td>
<td>10/20 (90)</td>
</tr>
<tr>
<td>MS pads lateral vertical</td>
<td>Rest</td>
<td>11.2 ± 4.4</td>
<td>7.0 ± 0.4</td>
<td>19/20 (95)</td>
<td>19/19 (100)</td>
<td>19/19 (100)</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>11.5 ± 4.1</td>
<td>7.1 ± 0.8</td>
<td>17/20 (85)</td>
<td>17/19 (90)</td>
<td>18/19 (95)</td>
</tr>
<tr>
<td>MS pads lateral horizontal</td>
<td>Rest</td>
<td>17.2 ± 6.8</td>
<td>7.0 ± 0.4</td>
<td>19/20 (95)</td>
<td>19/19 (100)</td>
<td>19/19 (100)</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>15.2 ± 5.8</td>
<td>7.0 ± 0.3</td>
<td>19/20 (95)</td>
<td>19/19 (100)</td>
<td>19/19 (100)</td>
</tr>
</tbody>
</table>

5.4.2 The amplitude of the heart rhythm signal

In the vertical midsternum position, which was the most reliable recording area, as well in the lateral vertical setting, the amplitude of the heart rhythm signal was approximately half (12.1± 4.5mm) that of the reference (22.6±7.4 mm). In the midsternum horizontal setup, it was even lower. The amplitude of the rhythm signal in the lateral horizontal position was clearly higher (17.2± 6.8 mm) than the amplitude of the rhythm signals recorded with the minimal-size pads in other positions (Table 10).
5.4.3 Quality of the recordings

The cardiologists judged the recordings performed at rest to be of better quality than those recorded during muscle tension. Despite the low amplitude in the mid-ternal vertical position, the quality of the recordings was graded as average/good even during muscle tension (rest: median 3 (IQR 3-3), tension: median 2 (IQR 3-2)). The quality of the recordings in the lateral horizontal position was also of high grade (Table 10).

5.4.4 Analysis time of the AED

The analysis time for manual measurement was ~7 s in the various positions (Table 10). In 11 out of the 200 ECG recordings, there were major artefacts interpreted as ventricular fibrillation (VF) by the AED. The time to analysis in these cases varied from 6.6 to 9.9 seconds (7.9±1.4 s).

5.5 DISCUSSION

This study shows that it is technically feasible to register bipolar ECGs recorded within an area the size of a mobile phone and to analyse them correctly and rapidly using the software of an AED. Use of this method by bystanders when communicating with the EMCC could lead to rhythm-based recognition of OHCA with high sensitivity.

The survival of patients following an OHCA depends on the sequence of interventions in the “chain of survival”, all of which must be optimised to maximise survival (Cummins, 1993). The most important factor in the “chain” is the time from collapse to the onset of resuscitation efforts, which depends considerably on identification of the OHCA by the bystander and/or by the EMD. Despite the efforts in research and periodic evidence-based revisions of clinical guidelines, the overall survival rate of patients with OHCA has remained low, ranging between 6.7 and 10.7% for all-rhythm CA (Sasson et al., 2010, Atwood et al., 2005). To strengthen the first part of the “survival chain”, it would offer a supplement resource for EMDs if the cardiac rhythm and the potential OHCA of an unconscious patient could be identified and confirmed with an automatically analysed bipolar ECG. This could be used to support the decisions the dispatchers must make with regard to what instructions to give to the bystander and which emergency medical responses to activate. Currently, these decisions are based largely on the standardised questions on OHCA symptoms, and the correct identification of cardiac arrest is made in ~80% of the OHCA cases (Nurmi et al., 2006, Lewis, Stubbs & Eisenberg, 2013). Nevertheless, by this method it is sometimes difficult or even impossible to recognize cardiac arrest (Lewis, Stubbs & Eisenberg, 2013). In the study by Kuisma et al. (Kuisma et al., 2005), survival until discharge in the case of VF was 37.2% if CA was correctly identified by the EMD and 28.6% if it was not. Furthermore, Berdowski et al. (Berdowski et al., 2009) found that the 3-month survival rate for all-rhythm OHCA was 14% if it was recognised correctly versus 5% if it was not.

Rhythm-based OHCA recognition could also save time. The mean time with the current method used by the EMD from the beginning of the emergency call to the recognition of OHCA (Kuisma et al., 2005, Lewis, Stubbs & Eisenberg, 2013) and the first dispatcher-assisted resuscitation efforts made by the bystander (Rea et al., 2001, Lewis, Stubbs & Eisenberg, 2013, Van Vleet & Hubble, 2012) is reported to vary from 75 to 240 s. Besides the reported mean time, there are always a few cases in which the recognition of an OHCA takes markedly longer, and as a fact, each cumulative minute of untreated CA reduces the likelihood of survival by 10–12% (Koster et al., 2010). In participants with normal sinus rhythm, the time to analysis with the AED was ~7 s in all of the recording positions that were used. In practice, the analysis of the ECG would take longer as the EMD would advise the layperson of the correct ECG recording position of the telephone and the recorded ECG or the ECG analysis result would be sent or reported over the mobile phone network to an EMCC. Both of these actions would prolong the final OHCA recognition time.

In the study by Puurtinen et al. (Puurtinen, Viik & Hyttinen, 2009), the best locations for positioning bipolar electrodes with a short interelectrode distance were studied. They found the best locations to be around the standard precordial leads V1-V4. In this study, the most reliable location for recording ECGs was vertically...
over the midsternum. Despite the fact that the QRS amplitude was approximately half that of the reference QRS amplitude, the vertical recordings over the sternum were of a good and acceptable quality, even during muscle tension. Indeed, they were even more reliable than the reference recordings with the normal-size pads. Placement of the pads vertically over the midsternum is feasible as there is no muscle and only a little subcutaneous tissue on top of the sternum. Moreover, it would be easy to locate in an emergency situation, even for a layperson.

In other ECG recording positions in this study, there was a disturbing artefact, especially during muscle tension. The horizontal position over the mid-sternum was the most unreliable location to record the ECG signal. The anatomy of the pectoral muscles made it difficult to adjust the pads properly in this position, and the pectoral muscles themselves created noise in the ECG during tension.

The recordings in the lateral horizontal position were reliable, and the amplitude of the QRS complex was greater than that recorded in the midsternal position. This corroborates the R-wave pattern in the standard 12-lead ECG and suggests that the lateral horizontal position could potentially be used in an emergency out-of-hospital setting. However, in one of the female volunteers, the AED could not detect an ECG signal in this position or in the lateral vertical position. This female volunteer was not obese, nor did she have breast prostheses, which otherwise might have explained the poor signal in the ECG. In this study, we did not use any skin preparations, which could have reduced the resistance of the skin and strengthened the ECG signal. At this point, we do not know the reason for the compromised signal in this particular volunteer.

In addition to gasping, convulsions and possible muscle tension there are also other possible sources of artefact and noise that can impair the ECG signal. The resistance and contiguity of the skin and the ECG electrodes varies among individuals. In emergency situations, the skin is unprepared; it may be hairy or oily, which can make the ECG recording vulnerable to artefact. Adipose tissue in obese patients is a potential insulator that may enhance the resistance of subcutaneous tissue. The effects of sweating and algid or cold skin and the mobile phone being connected during the recording of the ECG will have to be explored. The ability of the AED software to distinguish VF from other ECG patterns recorded from an area the size of a mobile phone needs to be evaluated in future experiments.

To function correctly, the ECG rhythm-based OHCA recognition should be easy to implement and almost completely automated. Even distressed laypersons or older people should be able to locate the appropriate position, on advice from the dispatcher, for the phone on the patient’s chest easily, and the ECG recording performed by the mobile phone should be automatically analysed and/or transmitted to the EMCC for analysis. The mobile technology and medically approved software already exist for the development of OHCA recognition with a mobile phone (Saxon, 2013). This technology has been introduced into medicine but can currently be utilised only for the detection of benign arrhythmias such as atrial fibrillation (Doarn & Merrell, 2013, Lau et al., 2013). When the previously mentioned challenges are overcome and the rhythm-based analysis of an ECG is reliable, we believe that it would be possible to improve and expedite the recognition of OHCA using this method, particularly for VF, which provides the best prognosis of all the OHCA types (Sasson et al., 2010, Atwood et al., 2005, Waalewijn, de Vos & Koster, 1998).

There are some limitations to this study. Because this is a preliminary study, the number of volunteers was limited to 20 and the participants were quite young, lean and healthy; thus, they did not represent the most common phenotype for CA. Cardiac dilatation or infarction of the myocardium may affect the QRS configuration and compromise its interpretation if the initial QRS amplitude is low. The low amplitude of QRS, especially if artefacts are present, may confuse the interpretation of ECG between asystole, VF and “normal” low-voltage ECG. The quality assessment of the ECG by the cardiologists was based on the opinions of experienced raters and was not standardised. This may weaken the reliability of the quality scoring. There are also limitations with regard to rhythm-based OHCA recognition. The software in an AED could determine whether or not the ECG rhythm is shockable; moreover, asystole could be probably recognised in the recording. However, for the identification of an OHCA that presents with a pulseless electrical activity rhythm, this type of method would not provide added value to the current practice.

Finally, in this study, ECG recordings were collected with customized pads and not by the mobile phone itself. The results of this study warrant the development of mobile phone platform and software for ECG analysis during out-of-hospital resuscitation.
5.6. CONCLUSIONS

This study shows that bipolar ECG can be recorded and analysed promptly with an AED from within an area the size of a mobile phone. The most reliable recording position was vertical at the midsternum level.
6 VENTRICULAR FIBRILLATION RECORDED AND ANALYSED WITHIN AN AREA THE SIZE OF A MOBILE PHONE: COULD IT ENABLE CARDIAC ARREST RECOGNITION?

6.1 ABSTRACT

6.1.1 Background

Recognition of out-of-hospital-cardiac arrests (OHCAs) at emergency medical communication centres is based on questions of OHCA symptoms, resulting in 50–80% accuracy rates. However, OHCAs might be recognised more promptly using “rhythm-based” recognition, whereby a victim’s cardiac rhythm is recorded with mobile phone technology that analyses and transmits recordings to emergency medical communication centres for further interpretation.

6.1.2 Objective

To examine whether the quality of normal cardiac rhythm and the rhythm with the best prognosis in OHCA, ventricular fibrillation (VF), is sufficient for “rhythm-based” OHCA recognition when recorded within a mobile phone-sized device.

6.1.3 Patients and methods

Electrocardiograms (ECGs) were recorded on 22 patients with normal cardiac rhythm and VF induced after the implantation of an internal cardioverter defibrillator. The rhythms were recorded at the mid-sternum within an area the size of a mobile phone and analysed by automated external defibrillator (AED) software and two cardiologists. The rhythms were categorised as shockable or nonshockable. The cardiologists assessed the quality of the recordings.

6.1.4 Results

The AED software correctly analysed all normal rhythms and 15 of 22 VF rhythms. The VF duration was too short for automatic detection in seven cases. The cardiologists analysed all the normal rhythms and VF sequences correctly and graded them as high quality.

6.1.5 Conclusions

The recordings of normal ECG rhythm and VF within an area the size of a mobile phone are of sufficient quality and could be used in “rhythm-based” OHCA recognition. The VF period was too short for an accurate analysis by the AED software in some cases.
6.2 INTRODUCTION

Prompt recognition of out-of-hospital cardiac arrest (OHCA) and immediate initiation of resuscitation efforts are critical to the survival of OHCA patients (Sasson et al., 2010). If cardiac arrest is not recognized by a bystander or an emergency medical dispatcher during an emergency call, then the chances of patient survival are reduced by ~7% every minute that passes without defibrillation (Waalewijn et al., 2001).

Currently, most emergency medical communication centres (EMCCs) recognize OHCA through symptoms. They rely on questions on the consciousness and breathing pattern of a patient (Hardeland et al., 2014). If unconsciousness presents without breathing or with abnormal breathing, then dispatchers should assume cardiac arrest and provide cardiopulmonary resuscitation (CPR) instructions by telephone. With bystander CPR, a patient’s survival chances increase by two-fold or three-fold (Sasson et al., 2010). Although the protocols for recognizing OHCA in EMCCs are designed to be simple, the recognition of OHCA is a challenge for dispatchers (Travers et al., 2014). At the most competent EMCCs, the rate at which OHCA is correctly recognised is as high as 90%; however, it commonly ranges between 50 and 80% (Garza et al., 2003, Vaillancourt et al., 2011).

Current technology enables electrocardiogram (ECG) data to be recorded and transmitted by mobile phone technology. Moreover, automatic rhythm analysis has been used for decades in automated external defibrillators (AEDs) and in implantable cardioverter defibrillators (ICDs). Until now, mobile phone technology has focused on atrial fibrillation recognition (Lau et al., 2013). However, the same technology applies to OHCA recognition. Thus, a bystander could record a bipolar ECG reading of a patient’s heart rhythm with a mobile phone, analyse the data using software installed on the phone and send the recording and/or analysed result within seconds over a mobile phone network to an EMCC. If medical dispatchers at EMCCs had access to such timely ECGs or ECG analysis to support their decisions, then OHCA recognition could be more accurate and save time in the process. The current symptom-based method can take minutes as opposed to the analysis time of, for example, the software of an AED usually ~10 s. (Travers et al., 2014).

The fundamental question is the quality of ECG readings recorded within a small area. The aim of this study was to evaluate whether the quality of bipolar ECG readings recorded within an area of a mobile phone is valid for ECG rhythm analysis carried out by cardiologists and AED software.

6.3 PATIENTS AND METHODS

6.3.1 Ethics, participants and sample size

This study was approved by the Ethics Committee of Kuopio University Hospital (Study 91/2012, 26 March 2013, ClinicalTrials.gov Identifier: NCT01824212). The hypothesis was that the quality of bipolar ECG readings recorded within an area the size of a mobile phone is good and that cardiologists and AED software can analyse ECG readings correctly to distinguish between shockable and non-shockable rhythms with an accuracy rate of 100%. The current system recognises ~80% of OHCA in EMCC. The target for OHCA recognition should be 100%. Using this target in sample size calculations, we compared the accuracy rate of 100% with the current accuracy rate of 80% for OHCA recognition at EMCC. According to the power calculations using a one-sided binomial test (risk level, 0.05; power, 95%), 22 observations would be required to detect differences between the expected success rate (99%) and the current success rate of 80%. Consequently, 22 patients scheduled to undergo ICD surgery were recruited. The patients provided their informed consent before participating. All patients were evaluated by cardiologists to be appropriate for induction of VF under sedation after implantation of the ICD. The characteristics of the participants are provided in Table 11.
Table 11. Characteristics of the patients. Numbers shown are data values or mean ±SD calculations.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Sex (male/female)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Length of sternum (cm)</th>
<th>Reason for implantable cardioverter defibrillator, primary/secondary prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td>58 ± 13</td>
<td>14 /8</td>
<td>80 ± 17</td>
<td>171 ± 8</td>
<td>22 ± 3</td>
<td>8/14</td>
</tr>
</tbody>
</table>

6.3.2 Study design

Before ICD implantation the height and weight of the patients as well the length of the sternum from the jugular notch to the xiphoid process were measured, and the midpoint of the sternum was marked. After the standard implantation procedure the patient’s spontaneous rhythm was recorded and printed with two AEDs. The first AED (R-series ALS; Zoll Medical Corporation, Chelmsford, Massachusetts, USA) recorded the rhythm vertically at the midpoint of the sternum with small ECG pads (3 × 3 cm, with a 3 cm distance between pads) cut from standard pads (CPR Stat-Pads; Zoll Medical Corporation, USA) to fit an area typical of a mobile phone (5 × 11 cm). Pads were trimmed to be just outside the wiring zone so that wiring remained intact for the recordings. The trimmed sternal pad served as the proximal electrode and the apical pad as the distal one. The centre of the electrode-free area was set at the midpoint of the sternum (Fig. 7).

Recordings with the second AED were performed with standard defibrillation pads placed at standard points on the body. The sternum electrode was placed below the right clavicle and the apical electrode was placed along the mid-axillary line below the left armpit (Fig. 7). The recordings were made at the same time as recordings made with the first AED, and served as a reference.

Patient sedation was induced by an intravenous administration of propofol (Propolipid® 10 mg/ml; Fresenius Kabi, Graz, Austria) after registration of a normal heart rhythm. VF was induced according to the standard procedure with 2 s of direct current, followed by automatic defibrillation induced by the implanted ICD (St Jude Medical, Saint Paul, Minnesota, USA; or Medtronic, Dublin, Ireland). During the VF period, ECG readings were recorded at the positions described previously. All ECG recordings were printed for later analysis.

Figure 7. ECG recording sites. Recordings with large standard pads were performed at standard points using small pads within an area the size of a mobile phone.
6.3.3 Measurements

Recordings collected with small electrodes at the midpoint of the sternum were classified with AED software as shockable or nonshockable. The size of the ECG amplitude of each recording was measured manually from the ECG printouts (mV). The reported amplitude was calculated as the average of five consecutive amplitudes taken from the middle of each recording.

The duration of VF was measured by the ICD as the sum of diagnosis time and ICD charge time. The time taken by the AED for rhythm analysis was measured manually with a chronometer. The chronometer was started when the rhythm analysis function of the AED was switched on and stopped when the AED displayed the recommendation to defibrillate or not. Results are reported as the mean ± SD values. The quality of all recorded ECG printouts was cross-checked and assessed by cardiologists. Both cardiologists graded each recording using a standardised scheme according to four quality factors (Table 12). Each factor was assessed on a scale of 0-2 such that each recording received a grade from each cardiologist between 0 and 8 (Table 12). The total quality score for each recording was calculated as the sum of the grades of both cardiologists and resulted in scores between 0 and 16. Scores were analysed to determine median and inter-quartile range (IQR) according to the recording position (small pads mid-sternum or standard pads on standard regions) and the recording state (basic rhythm or VF). In addition to assigning scores, cardiologists also identified the rhythm of the ECG print and classified the ECG readings as shockable or nonshockable rhythms.

The Wilcoxon signed-rank test was performed using IBM SPSS Statistics 23 software (IBM, North Castle, New York, USA) to evaluate the differences in the quality scores and the amplitudes in recordings of normal rhythm and VF with standard defibrillation pads placed at standard points or with small pads at the midpoint of the sternum. The significance level of the test was set to 0.05.

Table 12. Assessments of ECG recordings by cardiologists. The assessment of ECG recordings was divided into (A) rhythm analysis and (B) quality analysis according to set criteria. VF, ventricular fibrillation.

<table>
<thead>
<tr>
<th>A) Recognition of the rhythm</th>
<th>Is the rhythm shockable?</th>
<th>Yes/no</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Is the rhythm identifiable?</td>
<td>Yes/no</td>
</tr>
<tr>
<td></td>
<td>What is the rhythm in the ECG-print?</td>
<td>Correct/wrong</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B) Structured assessment of the ECG print</th>
<th>First impression of the readability and the overall quality of the ECG print</th>
<th>0 (badly)/ 1 (average)/ 2 (good)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Is the QRS configuration or equivalent (VF) identifiable?</td>
<td>0 (badly)/ 1 (average)/ 2 (easily)</td>
</tr>
<tr>
<td></td>
<td>The size of QRS configuration or equivalent (VF)?</td>
<td>0 (too small, hard to read)/ 1 (small but easy to read)/ 2 (suitable size, easy to read)</td>
</tr>
<tr>
<td></td>
<td>Amount of artefact or noise?</td>
<td>0 (noisy, hard to read)/ 1 (some artefact but easy to read)/ 2 (no remarkable artefact)</td>
</tr>
</tbody>
</table>
6.4 RESULTS

6.4.1 Rhythm analysis of the ECG recordings by the AED software

The AED’s rhythm analysis program was applied to all recordings with the small trimmed pads on the mid-sternum. Each patient’s normal heart rhythm was correctly classified as non-shockable in all AED analyses. In VF, the analysis was correct in 15 of the 22 (68%) cases. In the remaining seven cases, the duration of VF was too short for the AED to analyse the rhythm. The time taken by the AED to successfully analyse the rhythm was 8.3 ± 1.0 s for the normal heart rhythm and 10.8 ± 3.0 s for VF. The actual VF duration measured by the ICD was 12.2 ± 2.1 s (Table 13).

6.4.2 Quality of the recordings

Recordings with small pads placed at the mid-sternum were graded for quality from 9 to 16 for normal rhythm (IQR: 11.75–16; median: 14.5) and from 6 to 16 for induced VF (IQR: 10.75–14.25; median: 13). The amplitude of the QRS complex was 0.7 ± 0.4 mV for normal rhythm and 0.7 ± 0.3 mV for VF. Quality grades were slightly lower than grades of recordings with standard pads from standard sites (normal rhythm: IQR: 13–16; median: 14; P=0.844 and VF: IQR: 12–16; median: 13; P=0.304) and the amplitude of the QRS complex was lower than that of recordings with standard pads (P= 0.141 for normal rhythm and 0.293 for VF). However, the differences were not statistically significant (Figures 8 and 9 and Table 13).

![Figure 8](image_url)

Figure 8. Sum of cardiologists’ quality grades are represented as box plots. The possible sum of the quality grades of the both cardiologists was between 0 and 16. The P values of difference between the quality of ventricular fibrillation (VF) and normal rhythms recorded for mobile-phone-sized areas or normal areas were 0.304 and 0.844, respectively.
Figure 9. Patterns of ECG recordings. Recordings from a patient during normal rhythm and ventricular fibrillation with standard pads placed at standard points (recordings 1 and 3) and with small pads at the midpoint of the sternum (recordings 2 and 4). Amplification is 1.0 in recordings.

Table 13. Recognition, quality, size, analysis time and VF duration of the recordings. Result are shown as data values and percentages associated with the rhythm analysis recordings or as median and interquartile range values of the quality grade scoring. ECG amplitude, analysis time and the duration of ventricular fibrillation are presented as mean ± SD values. AED, automated external defibrillator; IQR, interquartile range; ND, not defined; VF, ventricular fibrillation.

<table>
<thead>
<tr>
<th>AED: shockable rhythm? (correct analysis)</th>
<th>Cardiologist: shockable rhythm? (correct analysis)</th>
<th>Cardiologist: rhythm identification (correct analysis)</th>
<th>Cardiologist: quality of the rhythm (median and (IQR))</th>
<th>ECG amplitude (mV)</th>
<th>Analysis time (s)</th>
<th>VF duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard position, normal rhythm</td>
<td>ND</td>
<td>22/22 (100)</td>
<td>18/22 (82)</td>
<td>14 (13-16)</td>
<td>0.9± 0.4</td>
<td>ND</td>
</tr>
<tr>
<td>Mobile phone size area, normal rhythm</td>
<td>22/22 (100)</td>
<td>22/22 (100)</td>
<td>14,5 (11,75-16)</td>
<td>0.7± 0.4</td>
<td>8.3±1.0</td>
<td>ND</td>
</tr>
<tr>
<td>Standard position, VF</td>
<td>ND</td>
<td>22/22 (100)</td>
<td>13 (12-16)</td>
<td>0.9± 0.4</td>
<td>ND</td>
<td>12.2±2.1</td>
</tr>
<tr>
<td>Mobile phone size area, VF</td>
<td>15/22 (88)</td>
<td>22/22 (100)</td>
<td>13 (10,75-14,25)</td>
<td>0.7± 0.3</td>
<td>10.8±3.0</td>
<td>12.2±2.1</td>
</tr>
</tbody>
</table>
6.4.3 Rhythm analysis of ECG recordings by the cardiologists

Cardiologists classified the ECG recordings correctly as shockable or non-shockable in all cases, as well as detected the primary rhythm (18 sinus rhythms and four atrial fibrillations) accurately in 18 of 22 recordings (82%) with standard pads and in 22 of 22 recordings (100%) with the small, trimmed pads used on the mid-sternum. The VF rhythm was diagnosed correctly in all recordings (Table 13).

6.5 DISCUSSION

The main finding of this study was that the quality of the ECG recordings of normal rhythm and VF is good when recorded from the mid-sternum within an area that is the size of a mobile phone. This supports the possibilities of a “rhythm-based” approach to OHCA in EMCC. This procedure could utilize ECG recordings with current mobile technology and software for analysis resulting in accurate and fast recognition of cardiac arrest. Although the AED’s software analysis had an accuracy rate of 68% (15/22 cases), all the ECG readings were of good quality according to the cardiologists. VF duration was too short for accurate AED analysis in seven cases. The induction of VF with 2 s of direct current created a short interruption in the ECG signal; therefore, the VF detected by the AED was ~2 to 3 s too short for AED analysis, although the actual duration of the VF period was long enough. This problem can probably be avoided in clinical practice with longer VFs and without the preceding interference of the VF induction procedure. The delays in the successful rhythm analysis of AED were short (~10 s).

Recognition of cardiac arrest is the first link in the chain of survival of OHCA. Without prompt OHCA recognition, there can neither be prompt resuscitation efforts nor good survival outcomes. The reported recognition rate of OHCA at EMCCs varies considerably. There are reports of EMCCs with OHCA recognition rates over 90% (Ma et al., 2007). However, the sensitivity of recognition is reported to be 70% for EMCCs on average (Vaillancourt et al., 2011). The recognition protocol is based on questions on OHCA symptoms. In this study, we approached cardiac arrest recognition from a different perspective. We showed that OHCA recognition could be based on the rhythms obtained during emergency calls. In this setting, only a small part of the cardiac muscle lies under the electrodes. Therefore, the electric potential difference between the electrodes may be low and the signal may be vulnerable to distortion (Janata et al., 2008). However, this study showed that with this method, good quality normal rhythm and VF could be recorded.

The OHCA recognition protocol in an EMCC should be sensitive and quick to identify patients experiencing OHCA. If OHCA is not recognised by a dispatcher or bystander, then CPR will be delayed until the arrival of emergency medical personnel. That situation prolongs the patient’s time without circulation and also decreases the incidence of VF rhythm, which has a better prognosis during OHCA. The overall survival rate of a CA patient deteriorates by 7–10% /min; hence, early resuscitation efforts may be crucial to CA patients (Waalewijn et al., 2001, Bobrow, Panczyk & Subido, 2012). Every second saved during recognition allows CPR to be initiated more promptly. In this study, ECG recordings provided quick analysis; this approach may therefore offer quicker recognition of OHCA compared with the current system. The current symptom-based protocol uses standardised questions for recognising OHCA at EMCCs and requires 1.15–3.39 min. The delay to the first CPR efforts is reported to be 2.30–5.30 min from the beginning of the emergency call. (Travers et al., 2014, Dami et al., 2015b, Clegg et al., 2014).

In our previous preliminary work, we considered the mid-sternum region as a simple and reliable position from which to register and analyse ECG recordings in an area the size of a mobile phone (Syvaoja et al., 2016). In the present study, the VF rhythm was also recorded from the same area with good quality. The recognition of cardiac arrest in cases of pulseless electrical activity (PEA) is challenging and relies on current protocols at EMCCs. Nevertheless, ECG recordings performing very low heart rates could assist EMCCs to recognise PEA in nonresponsive patients.

The American Heart Association has released a statement to improve emergency cardiovascular care with the use of digital strategies and innovative technologies (Rumsfeld et al., 2016). Software-based rhythm analysis has been used widely in AEDs and ICDs. Physiological data transmission technology has been utilised for remote monitoring of pacemakers or ICDs, for monitoring of ECGs for cardiac rehabilitation exercise.
sessions in patients with coronary artery disease and also for atrial fibrillation screening (Young, 2012, Lau et al., 2013). In addition, there are already mobile phone accessories with integrated electrodes that enable ECG registration with mobile phone (Lau et al., 2013). Perhaps we could combine these elements and use mobile technology and ECG transmissions for a rhythm-based approach to recognize OHCA more quickly for earlier initiation of CPR and for more accurate dispatch in EMCCs. The impact of this kind of approach to OHCA recognition deserves further research, which should focus on potential limitations of ECG recordings during real-life OHCA events (e.g. impact of environment and temperature, movement of the patient, victim characteristics and restrictions or limitations of bystanders), time consuming actions (e.g. undressing the patient and activating the phone) and the recognition of other OHCA rhythms (e.g. low-amplitude VF, ventricular tachycardia, asystole and PEA) with the novel system.

Although all components for this kind of rhythm-based OHCA recognition already exist, the full implementation of a new protocol would require both hardware and software developments in mobile phone technology. Furthermore, the distribution of the OHCA recognition method by mobile phone technology to EMCCs and to laypeople requires a great deal of effort.

Limitations of the study: The study population was limited and focused to patients with recently originated coarse VF. In sample size calculations, VF was used as the indicator rhythm of CA because it is probably the most dominant rhythm at the onset of cardiac arrest and because AED software can recognise it. The rhythm-based recognition of OHCA should also be applicable to asystole and PEA.

In this study, modified commercial gel ECG electrodes were used with a wired connection to the AED. That arrangement was stable and differs significantly from situations in which ECG recordings are made with phone-integrated dry electrodes and transferred through a wireless telephone network.

The measurements in this study were performed in the context of an operating theatre. However, in a less stable milieu, environmental interference could influence the quality of ECG recordings and subsequent rhythm analysis.

6.6 CONCLUSIONS

Recordings of normal ECG rhythm and VF within an area the size of a mobile phone appear to have sufficient quality for use in “rhythm-based” OHCA recognition. This could strengthen the first links in the chain of survival and improve cardiac arrest outcomes. The new approach to OHCA recognition deserves further study.
7 GENERAL DISCUSSION

The recognition of cardiac arrest at EMCCs is the first step in the chain of survival for patients with OHCA. Without the recognition of CA, actions cannot be taken in response to improve the prognosis of the patient. The recognition of CA should be followed by prompt and appropriate EMS dispatch, CPR instructions for bystanders and, when necessary, the encouragement of bystanders to perform CPR (Monsieurs et al., 2015, Sasson & Magid, 2015).

The recognition of OHCA depends on the EMD's over-the-phone evaluation of the level of consciousness and breathing pattern of the patient. Although actions required to recognise OHCA initially seem easy to perform, the evaluation of whether the patient is breathing normally frequently proves challenging for EMDs. According to research, the average sensitivity of such recognition is roughly 70%, albeit with considerable variability (Vaillancourt et al., 2011).

Continuing education and focus on abnormal breathing as described in the EMCC protocols and scripts can improve sensitivity in recognising abnormal breathing and, in turn, CA (Hardeland et al., 2017). However, the recognition of OHCA by merely evaluating the breathing pattern is a vulnerable challenge. It is possible that the ever-developing mobile technology can be mobilised to contribute to the process of recognising OHCA and supporting EMDs in their decision making in the future. This thesis was constructed with this invention and objective as the guideline in mind.

7.1 EFFECTS OF EMERGENCY DISPATCH RECOGNITION ON THE OHCA PATIENT’S CHAIN OF SURVIVAL

According to my study, the recognition of OHCA in the EMCC during the emergency phone call is essential and a vitally important performance to improve and optimise the survival rates of OHCA patients. Both the shorter response times of EMS units enclosed to the CPR instructions to bystanders and bystander CPR being performed more frequently before the arrival of professional help have lifesaving properties. The relative improvement in ROSC and hospital discharge were 23% and 44%, respectively, if the OHCA event was recognised in the EMCC. Another aspect worth noticing is the reality that almost one fifth of the patients in the category of not recognised (in the EMCC) OHCA patients, however, received CPR from aware bystanders. Thus, the magnitude of recognition that lead to bystander CPR can be even more obvious than reported here.

When a dispatcher at an EMCC recognises OHCA, the first step on the path to the possible survival of the patient has been taken (Viereck et al., 2017a). The dispatcher’s first act after the recognition is to send sufficient, appropriate EMS units as promptly as possible to the scene (Castren et al., 2008). As a result of the recognised cardiac arrest, the dispatched units become aware of the situation in the field and able to not only prepare for the mission but also conceive their mode of operation. When awareness of the mission is high, the subsequent performance of CPR can be adjusted accordingly.

Unconsciousness and convulsions are easily confused with cardiac arrest (Eisenberg, 2006, Dami et al., 2012). Although both conditions are categorised as having the highest priority at EMCCs, an auxiliary influence or boost occurs with the awareness of cardiac arrest. Such awareness is achieved when OHCA is recognised by the EMD, and, accordingly, the patient can be reached sooner (Nehme, Andrew & Smith, 2016). By the same token, the initial defibrillation can be performed earlier in a timeframe in which the probability of achieving ROSC improves (Gold et al., 2010, Waalewijn et al., 2001). The earlier the implementation of advanced life support for the patient, the better the opportunity of his or her survival (Nichol et al., 2016).

In addition to promptly dispatching EMS units into the field, EMDs should ensure that bystander-performed CPR is initiated whenever possible whilst EMS units are en route to the scene. Although CPR instructions may be needed even in cases in which bystanders know how to perform CPR, they are essential when bystanders are unaware of how to perform CPR. Apart from actual instructions, bystanders may also need encouragement and even force from EMDs to initiate the rather distressing procedure. Whether the
quality of bystander-performed CPR is better following the instructions or directions of EMDs, however, remains unknown (Bohm et al., 2011, Hagihara et al., 2018).

To improve the likelihood of survival for patients with OHCA, bystander-performed CPR should be initiated as soon as possible (Lewis, Stubbs & Eisenberg, 2013). Accordingly, over-the-phone instructions for bystanders should be announced and introduced clearly and quickly by the EMD. Several studies have suggested that ventilation is not essential during the initial minutes of resuscitation (Chandra et al., 1994). The arterial content of oxygen is considered to be sufficient in the onset of most OHCA events (Ewy, 2017). Currently, instructions for laypeople focus on CPR involving chest compression only instead of conventional CPR with rescue breaths (i.e. ventilation), the former of which increases the actual provision of bystander-performed CPR (Shimamoto et al., 2015, Perkins et al., 2015a). The protocol involving chest compression only is easier to learn, perform and remember, and the rate of survival of patients receiving CRP is comparable to, if not better than, that of patients who receive conventional CPR (Bobrow et al., 2010, Rea et al., 2010). From the EMD’s standpoint, conveying the instruction protocol for CPR involving chest compression only is also more straightforward and quicker than conveying the conventional protocol (Williams et al., 2006).

If the bystander is familiar and experienced with performing CPR, then CPR may be initiated even before the emergency call without any assistance or instructions from the EMD (Swor et al., 2006). In cases in which CPR instructions are given, bystander-performed CPR is thought to be the natural continuum to the chain of survival for the patient. However, not all cases in which instructions are given involve actual action, possibly because the EMS team has reached the patient before the bystander can initiate CPR or due to mental or real physical obstacles (Hauff et al., 2003). Other suggested causes for the relatively low CPR delivery rates (under 50% of OHCA events) include the bystander’s fear of causing harm or contracting an infectious disease, if not both, as well as the complexity of the psychomotor task, panic and the bystander’s reluctance to make mouth-to-mouth contact (Vaillancourt, Stiell & Wells, 2008, SOS-KANTO study group, 2007).

### 7.2 ECG QUALITY AND AUTOMATED ANALYSIS OF HEART RHYTHM WITH SIGNALS RECORDED IN AN AREA THE SIZE OF A MOBILE PHONE

In my study reported here, the quality of the ECG signal was good, and the rhythm was correctly analysed with the commercial software of a defibrillator within an area the size of a mobile phone. The most reliable place to perform the recordings was in the middle of the sternum, which, for EMDs, can facilitate instruction and, for laypeople, is easily located. Analysis was accurate even amidst the interference of standardised muscle tension, which is only one element of the various other sources of disturbance that could threaten the integrity of ECG signals. The findings of the experiment were encouraging and can provide the groundwork for additional studies, which should address the variable effect of different environmental circumstances and physiological features of patients upon the recording of ECG signals. However, the actual usability and required time per interval in the recognition process outside the hospital environment remains to be evaluated.

The ECG analysis of patients is a longstanding, well-defined practice in medicine, and the range of use of ECG recordings as well as their interpretations have been thoroughly described (Kligfield et al., 2007). Moreover, variables that cause distraction and interference in the quality of ECG signals are also known (Kligfield et al., 2007). Despite the traditional, well-known technique of ECG recording, a novel vision and approach to a constant practice require verification. My vision here is that, in the near future, ECG signals of good quality can be recorded promptly with mobile phones integrated with ECG electrodes. The registration could be automatically analysed by downloadable software in the phone or sent via the mobile phone network to an EMCC or other health care unit to be analysed there. The final objective of the vision is to strengthen EMD awareness of the situation in the field in order to support EMDs in their decision making. In the case of OHCA, the EMD recognition process can be supported and verified with ECG recordings of patients. Instead of symptom- and impression-based decision making, the judgement of EMDs could be based on recorded heart rhythms. Such recordings could also apply to other EMCC-dispatched and EMS-treated acute situations involving more benign arrhythmias, such as atrial fibrillation and supraventricular tachycardia. The physiological measure could be an element of the involved paramedic’s visualisation of the occurrence in the field. Currently, the measurement and control of various personal physiological variables is on the rise.
amongst laypeople. Amongst other applications, the arrhythmia-recognising supplemental capacity of personal phones could provide a platform for self-monitoring.

7.3 CARDIAC ARREST REGISTRATION IN A DEVICE WITH AN AREA THE SIZE OF A MOBILE PHONE

In conclusion of this part of my work, I state that the quality of the VF signal was reasonable in the recordings of our study population. The signal was also easily analysed automatically, provided that it lasted long enough (i.e. at least 10 s). Environmental interference in the stable operating theatre milieu was minimal during the ECG recording period, which ensured optimal recording circumstances. However, such circumstances hardly represent reality in the outside world, and the effect of different environmental characteristics (e.g. temperature and humidity) as well as patient-related conditions (e.g. gasping and seizures) have to be evaluated.

The initial idea of the thesis was to determine whether personal mobile phones, or smartphones, can be used in the recognition process of OHCA. In that context, the most important concern is whether the rhythms involved in cardiac arrest (i.e. ASY, PEA and VF) can be recorded with feasible quality from an area covered by a mobile phone. To explore that possibility, the rhythms needed to be available under controlled circumstances without compromising the health or treatment of the patient. VF was selected as the rhythm to evaluate for various reasons. First, controlled VF rhythms were induced after the implantation of the cardioverter defibrillator in the cardiological unit of the hospital, and patients in those cases were available to serve as participants in the study. Second, it can be supposed that the VF would be the initiator rhythm in the very early phase of OHCA more often than currently measured after the arrival of the EMS unit (Hara et al., 2015, Chamberlain, 2010, Hulleman et al., 2015). In reality, bystander-performed recordings could more often contain VF as the primary rhythm of OHCA, although VF as the initial rhythm recorded by EMS teams has decreased over time (Väyrynen et al., 2011, Herlitz et al., 2004, Hulleman et al., 2015). Third, VF as the initially recorded rhythm in OHCA has the best prognosis, provided that the CPR efforts are promptly initiated (Okubo et al., 2017). Last, ASY and especially PEA, as OHCA rhythms with clearly poorer prognoses (Saarinen et al., 2012, Väyrynen et al., 2008a) are, to some extent, more complex and challenging to attach to the rhythm-based OHCA recognition process. A very low frequency in the ECG could indicate a PEA rhythm; however, if the configuration of ECG is near normal and without additional information of the heart’s perfused status, it is impossible to distinguish PEA and normal ECG. Thus, introducing information about mechanical cardiac activity could resolve the dilemma of PEA. That kind of mechano-cardiographic analysis can be performed with accelerometers and gyroscopes, which are standard components of smartphones (Jaakkola et al., 2018). In the meantime, whilst awaiting the combined application of those technologies into a mobile phone, the recognition of OHCA, especially in the case of PEA, depends upon the symptom-based strategy and receives no added value from the rhythm-based approach.

In the case that ASY issues no electrical signal to be detected, and because unresponsive patients without ECG signal can be identified as victims of cardiac arrest, signal registration needs to be very reliably achieved. As mentioned earlier, the prognosis of ASY and PEA is poor; nevertheless, it is not hopeless and should not be ignored. When the recognition process and subsequent actions proceed quickly, and the patient is reached promptly by EMS personnel, then the prognosis of patient becomes reasonable (Chamberlain, 2010, Holmgren et al., 2010). Following OHCA with ASY or PEA as the initial rhythm, the survival to hospital discharge in our work was 12% (6 of 49) if the patient was reached in less than 5 min and 4.7% (26 of 553) if reached in 5–10 min. Despite the obstacles presented by PEA and ASY, the rhythm-based approach to OHCA recognition should also contain certain solutions to the issue of these rhythms.

To properly work, the represented rhythm-based OHCA recognition approach requires further development. However, the platforms for the rhythm-based recognition idea—namely, mobile phones—are widespread as well as widely used. The first draft of the software for OHCA recognition is already used in AEDs and implanted defibrillators, and electrodes ready for integration in mobile phones to record ECG signals are available for certain devices (Lau et al., 2013). In that sense, the pieces of rhythm-based OHCA recognition are available and need only to be combined. Yet, putting the idea into practice requires plenty of
resources from the market, and before investing, commercial developers tend to want projected revenues. At present, the possible recognition of OHCA in communities may not generate enough interest amongst laypeople to want to purchase the needed hardware and applications. However, the feature, whether attached or enclosed in a mobile phone, could be distributed as an added value with an attractive incentive, such as the possibility of more benign, everyday physiological measurements (e.g. arrhythmia sensations).

7.4 PRACTICES TO STRENGTHEN THE FIRST LINKS OF THE CHAIN-OF-SURVIVAL

The links in the chain of surviving OHCA should be as strong as possible. As the correct recognition of OHCA functions as a trigger for all subsequent actions in the chain, recognition should be as sensitive and prompt as possible. As mentioned earlier, despite the simplicity and ease of the recognition process, it is a challenging task for EMDs and involves several distracting elements. The question of whether the patient is breathing normally is vital in the recognition process of cardiac arrest. If the patient is unconscious and not breathing normally, then the situation should be identified as cardiac arrest (Hardeland et al., 2016, Travers et al., 2014). However, agonal breathing as well as possible convulsions during the first minutes of cardiac arrest may confound bystanders as well as EMDs (Eisenberg, 2006, Dami et al., 2012). Determining whether the patient is breathing at all, and if so, whether the breathing is normal is difficult for laypeople to judge. Therefore, the bystander’s reported opinion of the situation may be remarkably misguided and, in turn, misleading for the EMD. In response, education of EMDs about how to interview bystanders and focus on the assessment of breathing with appropriate predetermined questions can improve recognition sensitivity. Adherence to the locally used protocol (i.e. medical priority dispatch or criteria-based dispatch) without deviation is also associated with better recognition sensitivity (Heward, Damiani & Hartley-Sharpe, 2004). When the bystander is lucid, calm and clearly describes the event, the recognition of OHCA can be improved and the actions instructed in response promptly performed. However, if the bystander is anxious and experiences the situation as stressful or frightening, then recognition can become exceedingly problematic (Alfsen et al., 2015). In those cases, recognition could be supported by rhythm-based approaches to identifying OHCA. Objective ECG recordings, sent via mobile phone networks to EMCCs, could, therefore, be used to verify the impressions of EMDs.

The recognition of OHCA should precipitate bystander-performed CPR in the case of every patient with a reasonable prognosis and without do-not-attempt-resuscitation preferences (Kragholm et al., 2017). To put that objective into practice, some countries have taken initiatives to strengthen bystander-performed resuscitation attempts and advanced care (Okubo et al., 2017, Wissenberg et al., 2013). CPR can be spontaneously initiated by bystanders or realised after they receive instructions and the assistance of EMDs over the phone. The activation of bystanders may require more than CPR instructions, however; anxious bystanders might need encouragement and even force to take action to initiate CPR. To gauge the competence and motivation of bystanders involved in delivering CPR, a mobile-phone positioning system to dispatch lay volunteers trained in CPR was examined in Sweden (Ringh et al., 2015b). In that study, the rate of bystander-initiated CPR was 62% in the intervention group and 48% in the control group, thus the absolute difference for intervention versus control was 14%. Despite the significant difference in the bystander-performed CPR rate, the study was not powered enough to identify differences in the survival rates of patients.

Early defibrillation is the most important intervention for patients with a shockable heart rhythm and OHCA (Okubo et al., 2017). Accordingly, the placement of AEDs in the community as part of a publicly accessible defibrillation programme is recommended by international guidelines (Baekgaard et al., 2017, Perkins et al., 2015a). A systematic review has reported a median survival rate to hospital discharge of 40% for patients with OHCA defibrillated before the arrival of EMS by such programmes (Baekgaard et al., 2017). In cases of OHCA available for those programmes in Stockholm, Sweden, 70% of patients survived if a public AED was used, and both the structured AED programme and the spread of unregulated AEDs were associated with exceptionally high survival rates (Ringh et al., 2015b). AEDs are cost-effective at sites with a high density of both potential victims of cardiac arrest and resuscitators (Winkle, 2010). According to the American Heart Association and the ERC, publicly accessible defibrillators should be located in places where the possibility of OHCA is once every 2–5 years, which represents a type of frequency possible in urban areas (Folke et al., 2009).
In suburban and rural regions, by contrast, EMS and first-response delays are prolonged, and the defibrillation time in cases with shockable rhythms tends to be longer than approved times. The need for defibrillators is even more urgent in those regions than in urban areas. Accordingly, unmanned aerial vehicles or drones have been considered as solutions, since drones can fly with high velocity and potentially transport devices such as AEDs to the sites of OHCA, thereby making AEDs available to bystanders at the scene (Claesson et al., 2016).

In Finland, the number of publicly accessible defibrillators is modest compared to that in neighbouring countries such as Sweden and Denmark. The Sweden defibrillator register, or “Hjärtstartarregister”, consists of data of over 14,500 AED units. The accumulated number of AEDs sold in Denmark was estimated at 3,000 in 2006 and 15,000 in 2011 (Wissenberg et al., 2013b). In the national defibrillator registry of Denmark there were 7,800 AED units in 2012. However, local first responders (e.g. firefighters and border guards) are equipped with AEDs in Finland, meaning that defibrillation is often possible before EMS personnel reach the scene. The publicly accessible defibrillator design is one structure to also improve the survival of patients with OHCA in Finland. Responsibility of the initiation of AED programmes is under the supervision of national and/or regional public authorities.

Thus, basic life support (BLS) remains the critical factor in determining outcomes in OHCA (Kleinman et al., 2018). To implement the BLS for as many patients with OHCA as possible, large-scale resuscitation training for laypeople and children has to be implemented (Wingen et al., 2018, Wissenberg et al., 2013b) Self-instruction training kits, improved telephone guidance from emergency dispatch centres to bystanders witnessing a cardiac arrest, the addition of healthcare professionals at dispatch centres and the overall strengthening of EMS system, along with a large increase in the number of AEDs located outside hospitals are all initiatives to strengthen bystander-performed resuscitation attempts and advanced care whilst striving for the successful improved rate of survival of patients with OHCA (Wissenberg et al., 2013, Hansen et al., 2017). These approaches can be reinforced with a team of trained volunteer first responders or nearby laypeople with an AED from the vicinity. This kind of strategy could result in a situation where at least one of the first responders and the AED would arrive not just earlier than the traditional ambulance but within 5-6 minutes of the initial call (Schakow, Larsen & Henriksen, 2015).

7.5 STRENGTHS AND WEAKNESSES OF THE STUDY

This thesis aggregates various types of research from a large, prospectively collected registry cohort study to clinical studies with either volunteers or patients. The strength of the registry study, involving thousands of patients with OHCA, demonstrates the power of research in large populations, which stabilises individual variability in the registered events. As such, it provides a more reliable sample of the treatment process and the survival rate of patients with OHCA than an analysis of studies with smaller populations.

Despite the few administrators of the registry, because guidelines for completing data were strict, it can be supposed with confidence that the entered and registered data are reliable. However, for a registry survey, the data were collected over a relatively long period, and the structure of collected facts slightly changed over time. All collected data were registered manually; thus, the accuracy of data often depended on the exactness of intermediaries, paramedics and medical physicians. During the study period, improvements or changes in resuscitation care were implemented in practice. It was impossible to appraise the influence of the new practices on survival rates.

As for the clinical part of the study, the undisputed strength was the unrestricted envisioning of the recognition process of OHCA in the future. To date, mobile technology in the treatment process of OHCA has been used to locate OHCA events, dispatch lay responders to nearby OHCA, relay audio-visual animated CPR instructions to bystanders’ mobile phones and, of course, to transmit the instructions of EMDs to bystanders to perform CPR. The study thus involved boldly considering the possibility of extending the application of mobile phone technology to the recognition of OHCA. At the same time, the layout of the set of questions for the study was simple, as were the performed measures.

The obvious weakness of the clinical part of the study was its low number of examined volunteers and patients. The variability and diversity of people’s physiological features were greatly ignored in the preliminary studies, although the test milieu and physiological conditions of participants, despite their VF,
were stable during the recordings. Accordingly, the influence of temperature or other environmental factors were ignored during that stage of the study.

7.6 FUTURE PERSPECTIVES

The ability and competence of an EMS system to manage and care for patients experiencing OHCA have been conceived as measurements of the overall performance of the system. The recognition of OHCA emergencies is the catalyst of the survival process, for without the recognition of OHCA, action in response will not be taken. In this context, such an action consists of prompt dispatching and bystander-performed CPR. The education of the CPR-administering ability and willingness of bystanders to perform CPR will remain the foundation whilst striving to improve survival rates for patients with OHCA, despite the fact that the importance of bystander-performed CPR has also been argued by the medical community (Bardy, 2011).

Increasingly often, bystanders can be activated to engage in the CPR process in lieu of EMS personnel; for most people, before thinking selfishly, the basic instinct is to help other people. This preference or feature is worth to be set and used as part of the chain of survival as was done in Sweden and Denmark, where CPR-trained lay volunteers were dispatched to a nearby patient with out-of-hospital cardiac arrest (Ringh et al., 2015b, Schakow, Larsen & Henriksen, 2015).

The more active recruitment and education of youth in schools can be used to strengthen the team of CPR-motivated and -capable bystanders. The EMD’s recognition of OHCA, as well as the recognition process of many other conditions of people, will be supported with smart mobile devices or wearables that can measure far more physiological parameters than simply heart rhythm.

Although there is not yet sufficient experience to know the exactly future spread and use of personal mobile devices, it is reasonable to expect that society’s surroundings, homes, houses, cars, clothing, jewellery and accessories will all be monitoring and following mankind in the future (Baird, 2017). Technology in the future will likely consist of personal devices as well as handheld and movable applications that will authorise individuals to monitor their physiology from anywhere and transmit the information directly to health care providers, if necessary (Horn, 2017). Such variable measurements will be able to provide feedback to the users of the novel technology, warn them of alarming results of the measurements and even call for help in certain circumstances. As a result, increasing remote communication with healthcare providers will reduce the need for personal visits. Since the community cannot afford to continue investing billions to keep the persistently growing and ageing population healthy, healthcare technologies that solve the challenge of economical demands, cost-effectivity and affordability will be able to achieve a position in healthcare in the future. In the years ahead, everyone in the area of healthcare will have to prove that their new and innovative products or services are able to deliver better outcomes than the alternatives (Rhea, 2017).

The heart rhythm-based recognition of OHCA will be further studied and could be integrated as part of the chain of survival process to support EMDs in their work. The possibility of splitting and recoding the touchscreens of mobile phones or devices to ECG electrodes would allow to use the rhythm-recognising applications without accessories. A scheme or design that requires only the smartphone app would allow a far easier route to distribute the new approach.

Cardiac arrest as a form of dysrhythmia, though the most hazardous, is only the tip of the iceberg of arrhythmias. Whether the experienced dysrhythmia is benign is impossible to judge without documenting the rhythm. Supraventricular arrhythmias or paroxysmal atrial fibrillation is often challenging to detect if the ECG recording is impossible to read when the patient experiences or senses dysrhythmia. Furthermore, asymptomatic atrial fibrillation is increasingly common in the ageing population and implicated in many forms of ischemic stroke. The earlier identification of asymptomatic atrial fibrillation with appropriate anticoagulation may decrease stroke morbidity and mortality (Halcox et al., 2017). The arrhythmia-recognising platform of mobile devices will thus prove their value in the diagnostic process or screening of those dysrhythmias.

Handheld devices, single-channel ECGs and photoplethysmographical pulse waves have been researched and are partly available to detect and recognise certain dysrhythmias and ischemia of the heart (Muhlestein et al., 2015, Nemati et al., 2016, Guzik & Malik, 2016). The pieces of technology to remote rhythm-based OHCA
recognition are also available. They are just waiting for the opportunity and occasion to breakthrough to be a part of the OHCA recognition process.
8 CONCLUSIONS

As the catalyst of the chain of survival for patients with OHCA, recognition of OHCA by dispatchers at EMCCs has been associated with reduced response times by EMS, increased rates of bystander-performed CPR as well as achieved ROSC and improved rates of survival for patients. When cardiac arrest was recognised by EMCCs, rates of achieved ROSC and survival to hospital discharge were 49% and 23%, respectively; however, when it was not, those rates dropped to 40% and 16%. Open-minded efforts to promote and improve the recognition of OHCA as the initial step in the survival process for patients with OHCA are, therefore, strongly recommended.

Bipolar ECGs of good quality can be recorded by using devices with an area the size of a mobile phone. Although the average amplitude of the recordings was low, the software of the AED could analyse the recorded rhythms promptly, even amidst the interference of muscle tension. The most reliable recording position was vertical at the mid-sternum level. Such recordings accomplished in a small area of the body, could apply to automatic, remote or next-to-patient rhythm analysis.

Recordings of normal ECG rhythm and VF within an area the size of a mobile phone appear to have sufficient quality for use in rhythm-based OHCA recognition. Such an approach could improve the success rate of the first essential steps in the chain of survival of patients with OHCA and improve cardiac arrest outcomes. In that sense, the proposed operating model for OHCA recognition deserves further study.
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Recognition of out-of-hospital cardiac arrest (OHCA) is vital for victims. During the emergency call, dispatchers’ recognition of OHCA relies on answers provided about cardiac arrest symptoms. However, OHCAs might be recognised more exactly using mobile phone technology which records and analyses a victim’s cardiac rhythm (rhythm-based approach). This thesis describes the impact of OHCA recognition on survival rate and considers the option of using mobile technology to help recognise OHCA.