

HEIDI HELLEVUO

Studies on the Aetiology, Quality, and Outcome of Cardiopulmonary Resuscitation

With special reference to resuscitation-associated complications and quality of life after cardiac arrest

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Outcome of Cardiopulmonary Resuscitation
*With special reference to resuscitation-associated
complications and quality of life after cardiac arrest*

ACADEMIC DISSERTATION

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ACADEMIC DISSERTATION

Tampere University, the Faculty of Medicine and Health Technology
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ABSTRACT

For the prognosis of a cardiac arrest patient, it is crucial that all the steps, from recognition of the arrest to the rehabilitation, proceed without delays or disruptions. As part of a high-quality cardiopulmonary resuscitation (CPR), it is important to identify the underlying reason for the arrest in order to allow the selection of specific treatment interventions. Unfortunately, the quality of CPR is often suboptimal. One solution to this problem can be the use of audio-visual feedback devices. Deeper chest compressions correlate with better defibrillation rates and the likelihood of a return of spontaneous circulation but, at the same time, can cause more injuries to the chest and upper abdominal area.

The aetiology of in-hospital cardiac arrests on general wards and their preceding vital dysfunctions and subjective antecedents associated with 6-months survival were examined in the first sub-study. In 141 events, the aetiology was determined as cardiac, 73 of which were due to acute myocardial infarction. In 138 cases, the cause was due to a non-cardiac reason; the most common causes were exsanguination (16) and pneumonia (39). No differences were observed in the incidence of objective vital dysfunctions preceding the event between the cardiac and non-cardiac groups (40 % vs. 44 %, $p = 0.448$). In the cardiac cohort, subjective antecedents were more common (47 % vs. 32 %, $p = 0.022$). Only monitored or witnessed events, low comorbidity score and shockable primary rhythm were independently associated with 180-day survival.

In the second sub-study, the quality of CPR during transportation was analysed. 24 paramedics performed chest compressions on a Laerdal Resusci Anne® manikin first without and then with the guidance of Philips HeartStart MRx defibrillator and with high-quality cardiopulmonary resuscitation (QCPR) feedback device. With the feedback device, compression depth improved from 51 (10) mm to 56 (5) mm ($p < 0.001$). However, no differences were observed in the chest compression rate ($p=0.55$) and no-flow fractions ($p=0.82$). When the mattress effect was taken into account, the real chest compression depth was only 41 (8) mm in non-feedback phase and 44 (5) in feedback phase ($p < 0.001$).

In the third sub-study the mattress effect was analysed during ten separate in-hospital resuscitation attempts. The mean chest compression depth in every

resuscitation attempt was over 50 mm. When the mattress effect was taken into account and the real chest compression depth was calculated, the real chest compression depth was adequate in CPRs performed on a standard gel mattress and emergency room stretcher, but on an intensive care unit (ICU) air mattress the real chest compression depth fell below 50 mm.

The potential association between CPR-related injuries and objectively measured chest compression depth was investigated in the fourth sub-study. The data of 170 separate resuscitation attempts with the details of actual chest compression depths and postresuscitation computed tomography (CT)-scans, thorax X-rays or medical/forensic autopsy findings were analysed. Injuries were found in 32 % of the patients. The majority of the injuries were spontaneously healing rib or sternal fractures. When the mean chest compression depth exceeded 60 mm, the percentage of the injuries increased from 27 to 49 % ($p=0.06$). With the implementation of 2010 resuscitation guidelines, an increase in the percentage of the injuries was seen from 32 to 40 % ($p=0.21$). None of the injuries contributed to the death of the patients or affected survival.

In the fifth sub-study, the quality of life six months after a successful cardiac arrest and factors that might influence a better outcome were investigated. Altogether 222 patients were admitted to the ICU after a cardiac arrest. After six months 79 (36 %) patients were still alive, and 25 % answered to the follow-up EuroQoL-5 Dimensions (EQ-5D) questionnaire. When the possible factor influencing the quality of life was analysed, the best predictor for a good quality of life after cardiac arrest was a good quality of life prior to cardiac arrest.

It can be concluded that in-hospital cardiac arrests are, in most cases, due to cardiac reasons that should be taken into account when considering specific treatment options during or after CPR. The quality of CPR can be improved by using audio-visual feedback devices. The downside of these devices is that when the patient is lying on a compliant surface, the real chest compression depth can be too shallow. Current resuscitation guidelines emphasise high-quality chest compressions with a depth of 50-60 mm. Deeper chest compressions are associated with an increased risk of injuries. The majority of the injuries are spontaneously healing rib or sternal fractures, and life-threatening complications occur infrequently. On the basis of this study, it can be suggested that the maximum depth recommended should be 6 cm because there is no data suggesting that even deeper compressions would be beneficial; however, they are likely to increase the risk of injuries. Patients that survive cardiac arrest have, on the average, a good quality of life six months after the cardiac arrest.

TIIVISTELMÄ

Jotta sydänpysähdyspotilaan ennuste olisi paras mahdollinen, tulisi hoitoketjun tilanteen tunnistamisesta aina jatkohoidon ja kuntoutuksen päättymiseen saakka sujua moitteettomasti. Osana laadukasta elvytystapahtumaa tulisi miettiä sydänpysähdykseen johtanutta syytä ja aloittaa tarvittava hoito. Elvytyksen laadun on usein todettu olevan heikkoa, mutta laatua voidaan parantaa elvytystä ohjaavilla laitteilla. Syvempien paineluiden on todettu olevan yhteydessä kammiovärinänsä parempaan defibrilloitumiseen ja spontaanin verenkierron palautumiseen, mutta samalla potilaalle voidaan mahdollisesti aiheuttaa vammoja rintakehän ja ylävatsan alueen alueelle.

Ensimmäisessä osatyössä analysoitiin vuodeosastolla tapahtuneiden sydänpysähdysten syyt, niitä edeltäneet oireet ja vitaaliparametrien muutokset sekä näiden yhteys 180 päivän elossa olon kanssa. Sydänperäinen syy todettiin 141 potilaalla ja näistä 73 taustalla oli sydäninfarkti. Lopulla 138 potilaalla elottomuuden syy oli ei-sydänperäinen, joista suurinta ryhmää edusti keuhkokuume (39) ja verenvuodot (16). Potilaan ilmoittamat ennako-oireet olivat yleisimpiä sydänperäisen elottomuuden ryhmässä (47 % vs. 32 %, $p = 0.022$). Koko potilasryhmässä vain defibrilloitava lähtörytmi, monitoroitu/silminnäkijän havaitsema elottomuuden alku ja matala komorbiditeetti assosioituivat 180 päivän elossa oloon.

Toisessa osatyössä tutkittiin elvytyksen laatua ambulanssikuljetuksen aikana. 24 ensihoitajaa osallistui tutkimukseen elvyttämällä Laerdal Resusci Anne®-elvytysnukkea puolet matkasta ilman laatua ohjaavaa defibrillaattoria, ja loppumatkassa elvytystä ohjattiin Philipsin HeartStart MRx defibrillaattorin ja elvytyksen laatua ohjaavan (QCPR) -ohjaimen avulla. Kun elvytystä ohjattiin QCPR-ohjaimen avulla, painelussyvyys parani 51 (10) mm:stä 56 (5) mm:iin ($p < 0.001$). Kun potjan ja parien painuminen elvytysnukkeen alla huomioitiin, oli keskimääräinen painelussyvyys vain 41 (8) mm ilman ohjausta ja 44 (5) QCPR-ohjauksen kanssa ($p < 0.001$).

Kolmannessa osatyössä tutkittiin potjan painumista kymmenessä sairaalassa tapahtuneiden elvytysten aikana. Keskimääräinen painelussyvyys jokaisessa elvytyksessä ylitti suositellun minimisyvyyden 50 mm. Kun potjan painuminen huomioitiin todellista rintakehän painelussyvyyttä arvioidessa, saavutettiin

geelipatjalla ja ensiavun paareilla riittävä syvyys, mutta teho-osaston ilmapatjalla painelussyvyys alitti suositellun 50 mm.

Neljännessä osatyössä analysoidtiin painelussyvyyden ja rintakehän sekä ylävatsan alueen vammojen yhteyttä. Yhteensä 170 potilaan osalta analysoidtiin paineluelvytyksen aikainen painelussyvyys sekä mahdolliset vammalöydökset elvytyksen jälkeen tehdyistä kuvantamistutkimuksista tai ruumiinavaustiedoista. Paineluelvytyksen aiheuttamia vammoja todettiin 32 %:lla potilasta. Suurin osa näistä oli spontaanisti paranevia kylkiluumurtumia ja rintalastan murtumia. Kun painelussyvyyden yhteyttä tarkasteltiin vammoihin liittyen, todettiin, että keskimääräisen painelussyvyyden ylittäessä 60 mm, vammojen määrä lisääntyy 27 %:sta 49 %:iin ($p=0.06$). Vuonna 2010 julkaistujen, ja Suomessa vuonna 2011 käyttöön otettujen, elvytys-suositusten ja lisääntyneen painelussyvyyden myötä vammojen määrä lisääntyi 32 %:sta 40 %:iin. Yhdenkään vamman ei todettu aiheuttaneen potilaan kuolemaa tai vaikuttaneen potilaan selviämiseen.

Viidennessä osatyössä analysoidtiin sydänpysähdyksestä elvytetyn potilaan elämänlaatua kuusi kuukautta elvytystapahtuman jälkeen ja analysoidtiin tekijöitä, jotka voivat mahdollisesti vaikuttaa potilaan elämänlaatuun elvytyksen jälkeen. Yhteensä 222 potilasta hoidettiin tutkimusaikana teho-osastolla elvytyksen jälkeen. Kuuden kuukauden kohdalla 79 (36 %) potilasta oli edelleen elossa ja näistä potilasta 55 (25 %) vastasi EuroQoL (EQ-5D) elämänlaatuselvitykseen. Elämänlaatua arvioitiin käyttämällä -kyselyä. Kun analysoidtiin tekijöitä, jotka vaikuttavat potilaan elämänlaatuun elvytyksen jälkeen, todettiin, että vain hyvä elämänlaatu ennen elvytystä ennustaa parempaa elämänlaatua elvytyksen jälkeen.

Tämän väitöskirjatutkimuksen loppupäätelminä voidaan todeta, että sairaalan sisällä tapahtuvissa elvytyksissä elvytyksen syy on useimmiten sydänperäinen ja tämä tulisi huomioida elvytyksen aikana, kun mieltii sydänpysähdykseen kohdennettavaa hoitoa. Lisäksi voidaan todeta, että elvytyksen laatua voidaan parantaa käyttämällä laatua ohjaavia elvytysvälineitä, mutta pehmeän alustan aiheuttama vääristymä todellisessa painelussyvyudessa tulisi huomioida. Paineluelvytykseen liittyvät vammat ovat spontaanisti paranevia ja vain harva saa hengenvaarallisen komplikaation. Potilailla, jotka selviävät sydänpysähdyksestä, on varsin hyvä elämänlaatu, kun elämänlaatu oli arvioitu kuusi kuukautta elvytyksen jälkeen.

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ORIGINAL PUBLICATIONS

The thesis is based on the following five original publications referred to in the text by their Roman numerals I to V.

- Publication I Tirkkonen J, Hellevuo H, Olkkola KT, Hoppu S. Aetiology of in-hospital cardiac arrest on general wards. *Resuscitation* 2016;107:19-24.
- Publication II Hellevuo H, Sainio M, Huhtala H, Olkkola KT, Tenhunen J, Hoppu S. The quality of manual chest compressions during transport - effect of the mattress assessed by dual accelerometers. *Acta Anaesthesiol Scand* 2014;58:323-8.
- Publication III Sainio M, Hellevuo H, Huhtala H, Hoppu S, Eilevstjønn J, Tenhunen J, Olkkola KT. Effect of mattress and bed frame deflection on real chest compression depth measured with two CPR sensors. *Resuscitation* 2014;85:840-3.
- Publication IV Hellevuo H, Sainio M, Nevalainen R, Huhtala H, Olkkola KT, Tenhunen J, Hoppu S. Deeper chest compression - more complications for cardiac arrest patients? *Resuscitation* 2013;84:760-5.
- Publication V Hellevuo H, Sainio M, Huhtala H, Olkkola KT, Tenhunen J, Hoppu S. Good quality of life before cardiac arrest predicts good quality of life after resuscitation. *Acta Anaesthesiol Scand* 2018;62:515-21.

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ABBREVIATIONS

AED	Automated External Defibrillator
ALS	Advanced Life Support
AMI	Acute Myocardial Infarction
ASY	Asystole
BLS	Basic Life Support
BMI	Body Mass Index
CA	Cardiac Arrest
CABG	Coronary Artery Bypass Grafting
CC	Chest Compression
CCI	Charlson Comorbidity Index
COPD	Chronic Obstructive Pulmonary Disease
CPC	Cerebral Performance Categories Scale
CPR	Cardiopulmonary Resuscitation
CT	Computed Tomography
EMS	Emergency Medical Services
EQ-5D	EuroQoL-5 Dimensions Questionnaire (self-report questionnaire)
EQIndex	Quality of Life Index
ER	Emergency Room
ERC	European Resuscitation Council
HB	Hospital Bed (standard, gel mattress)
HRQoL	Health-Related Quality of Life
ICD	Implantable Cardioverter-Defibrillator
ICU	Intensive Care Unit
ILCOR	International Liaison Committee on Resuscitation
IHCA	In-Hospital Cardiac Arrest
MET	Medical Emergency Team
OHCA	Out-of-Hospital Cardiac Arrest
PAMA	Cardiac Pacemaker
PPCI	Primary Percutaneous Coronary Intervention

PEA	Pulseless Electrical Activity
QCPR	High Quality Cardiopulmonary Resuscitation
QoL	Quality of Life
ROSC	Return of Spontaneous Circulation
SCA	Sudden Cardiac Arrest
STEMI	ST-Segment Elevation Myocardial Infarction
Tays	Tampere University Hospital (Tampereen yliopistollinen sairaala)
TH	Therapeutic Hypothermia
TTM	Targeted Temperature Management
VA-ECMO	Venoarterial Extracorporeal Membrane Oxygenation
VAS	Visual Analogue Scale
VF	Ventricular Fibrillation
pVT	Pulseless Ventricular Tachycardia

1 INTRODUCTION

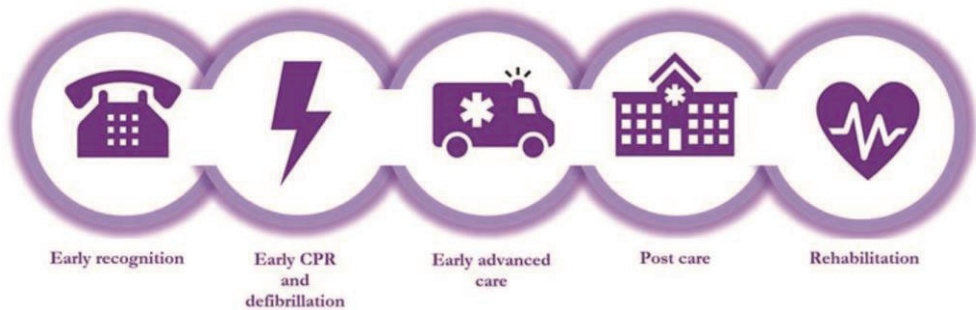


Figure 1. The Chain of Survival. Modified from ERC Guidelines 2015.

Cardiopulmonary resuscitation (CPR) requires good teamwork. The chain of survival is only as strong as its weakest link (Fig 1.). Therefore, all links, from the early recognition of cardiac arrest (CA) to post-resuscitation care and rehabilitation, are equally important. (Monsieurs 2015.) Despite the recent medical innovations, the survival of CA patients has remained poor. 30-day survival of cardiac arrest patient is approx. 10 % (Akintoye 2020; Doan 2020; Nolan 2014; Sandroni 2007; Schlupe 2018.). Out-of-hospital cardiac arrests (OHCAs) are often caused by cardiac reasons, whereas in-hospital cardiac arrests (IHCAs) are thought not to be (Perkins 2015). The outcome of the resuscitation attempt is strongly affected by the quality of the CPR (Christenson 2009; Goharani 2019; Nolan 2006; Nolan 2014; Stiell 2012; Wik 1994). The quality of CPR is often poor, and resuscitation under special circumstances, such as ongoing resuscitation during transportation, may even worsen the quality (Beom 2018; Chung 2010). A compliant mattress or bed underneath the patient can diminish the depth of the chest compressions (Lin 2017; Nishisaki 2009; Noordergraaf 2009). With deeper chest compressions, we can increase the success rate of defibrillation and the return of spontaneous circulation (ROSC), but we may also increase the number of iatrogenic injuries (Edelson 2006; 2008; Kim 2011). Even though the success rate of resuscitation attempts is poor, the

patients who survive from CA seem to have a good or at least acceptable quality of life according to Beesems (2014), Kearney (2019), Kimmoun (2020) and Meaney (2013).

The goal of this thesis was to investigate the aetiology of in-hospital cardiac arrests and analyse if the aetiology and possible preceding vital dysfunctions are associated with long-term survival. The second aim was to analyse the quality of CPR in a moving vehicle and on a compliant surface and investigate if audio-visual feedback devices improve the quality of CPR during transportation. Furthermore, it was considered important to examine the possible injuries caused by chest compressions and the quality of life of CA patients six months after a successful CPR.

2 REVIEW OF THE LITERATURE

2.1 Cardiopulmonary Resuscitation

In the eighteenth century, centuries before the new era of CPR, it was thought that inflation and deflation of the lungs were the keys to restoring life after CA (Julian 1975). The first experimentations with open-chest cardiac massage on dogs were made in 1874, and soon thereafter closed-chest cardiac massage was performed in cats. ‘The father of cardiac compression’, Dr Franz Koenig, a professor of surgery, reported six successful resuscitation attempts on humans in 1885. (Jude 1961; 1964.) It took nearly one hundred years before Kouwenhoven et al. (1960) combined chest compressions (CC) and artificial respiration to the defibrillation of the heart.

Even though the triumph of medical developments has revolutionised many aspects of modern medicine in recent decades, manual CCs have remained the cornerstone of CPR. The International Liaison Committee on Resuscitation (ILCOR) was established in 1992. Since then it has brought together professionals in resuscitation science to work side by side and collaborate with resuscitation councils worldwide. ILCOR’s first consensus statement on international resuscitation guidelines was published in 2000, and international science and treatment recommendations followed in 2005. For the first ten years, the science and treatment recommendations were revised in a five-year cyclic process. From 2017, the science and treatment recommendations have been published in an annual series (Olasveengen 2017; Soar 2018; 2019). In 2010, the resuscitation guidelines placed a strong emphasis on high-quality CCs. The recommended compression depth increased from 38–52 mm to 50–60 mm, and the compression rate stayed at 100 compressions per minute. (Hazinski 2010.) In 2015, the resuscitation guidelines underlined the importance of CCs but stated that CC should not exceed 6 cm (Nolan 2015).

The quality of CCs is shown to affect the outcome of CPR. With deeper chest compressions, a higher rate of ROSC and successful defibrillation can be achieved. (Edelson 2006; 2008; Kim 2011.) Also, the percentage of survival increases with deeper compressions (Stiell 2012), but how this translates to a better quality of life after CA is yet unknown.

2.1.1 Adult Basic Life Support

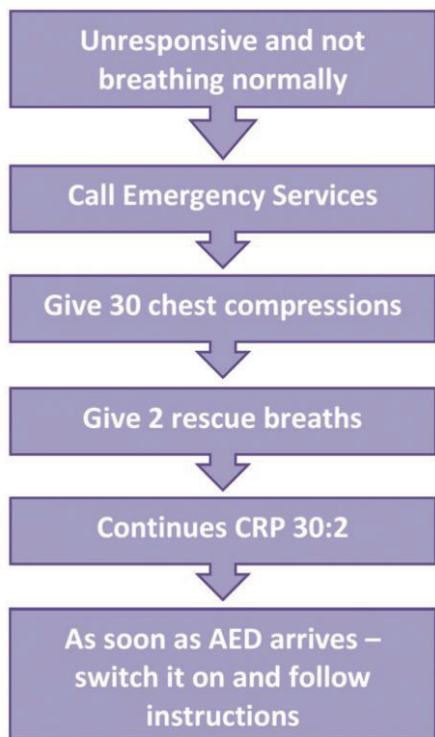


Figure 2. Adult Basic Life Support algorithm. Modified from ERC Guidelines 2015.

The person who is not breathing normally and is at the same time unresponsive is considered to have CA and require CPR. Checking the pulse in the carotid artery, or any artery, has been shown to be an inaccurate method of verifying the presence of circulation, and futile efforts in pulse checking delay CPR. (Bahr 1997; Moule 2000; Tibballs 2009.) It is important that emergency medical services (EMS) are dispatched immediately, and that high quality CPR is continued with minimal or no pauses. When the heart stops beating, brain and heart are starved from blood and oxygen. With CCs, critical blood flow to the vital organs can be achieved, and the likelihood of the heart resuming its normal rhythm after defibrillation increases. (Edelson 2006; 2008.) Adult basic life support (BLS) is used when initiating resuscitation on adult CA victims. The resuscitation guidelines include steps for the management of the airway,

breathing and circulation.

Basic steps when encountering a possible CA victim involve checking for a response, opening airways using the head tilt and listening for sounds of normal breathing. If the victim is unresponsive, call for help and, in a presence of a second lay person, send for an automated external defibrillator (AED). After the emergency service call, perform 30 uninterrupted chest compressions with a rate of 100–120/min and a depth of 5 to 6 cm, and let the chest recoil fully during the compression cycle. If trained and able/willing, perform two rescue breaths after each cycle of 30 chest compressions. If and when the AED arrives, switch it on, attach the electrodes and follow the directions and continue chest compressions with no of minimal pauses.(Perkins 2015.) The adult BLS algorithm is summarised in Figure 2.

2.1.2 Adult Advanced Life Support

If ROSC is not achieved during BLS, medical personnel continue the resuscitation using Advanced Life Support (ALS) algorithms (Fig. 3). The transition from BLS to ALS should go seamlessly. In ALS algorithm, the basic BLS principles apply, high quality CPR is continued with no or minimal interruptions. The algorithm is distinguished between shockable and non- shockable rhythms. The 2 min cycle is similar in both rhythm groups and assessment of the rhythm is always performed after each cycle.

Airways are secured with tracheal intubation only by skilled and properly trained healthcare personnel. If no skilled personnel is available, airways can be secured with supraglottic airway (e.g. i-gel, laryngeal mask airway, laryngeal tube). After securing airways, and correct position of the tube is confirmed, chest compressions are continued at the rate 100-120/min and ventilation of the lungs 10/min. If supraglottic airway leaks during continuous chest compressions and ventilation becomes insufficient, the chest compressions are performed in 30:2 ratio with the ventilation. Tracheal intubation or placement of supraglottic airway must not delay defibrillation. If short pause is required, when tracheal intubation tube is inserted, no more than 5 s pause is allowed. End-tidal carbon dioxide with waveform capnography should be used as part ALS protocol.

Intravenous or -osseous access for drugs and fluids is established. Adrenalin is administered to patients with non-shockable initial rhythm as soon as intravenous or -osseous access is established. When the initial rhythm is shockable, 1mg of adrenalin is administered after the third shock, and then repeated every 3–5 min during cardiac arrest. Anti-arrhythmic drug amiodarone (300 mg) should be administered after the third defibrillation if ventricular fibrillation (VF) or pulseless ventricular tachycardia (pVT) continues. Further dose 150mg can be administered if VF/pVT continues after five defibrillations. Lidocaine can be used as alternative for amiodarone.

Alongside high-quality CPR, it is important to treat potential underlying causes or aggravating factors. 4H4T are listed in figure 3. The use of ultrasound during CPR might help to detect reversible causes, e.g. cardiac tamponade, pulmonary embolism. Mechanical chest compressions, extracorporeal CPR, periarrest coronary angiography should be considered as a rescue therapy in selected patient groups.

Advanced Life Support

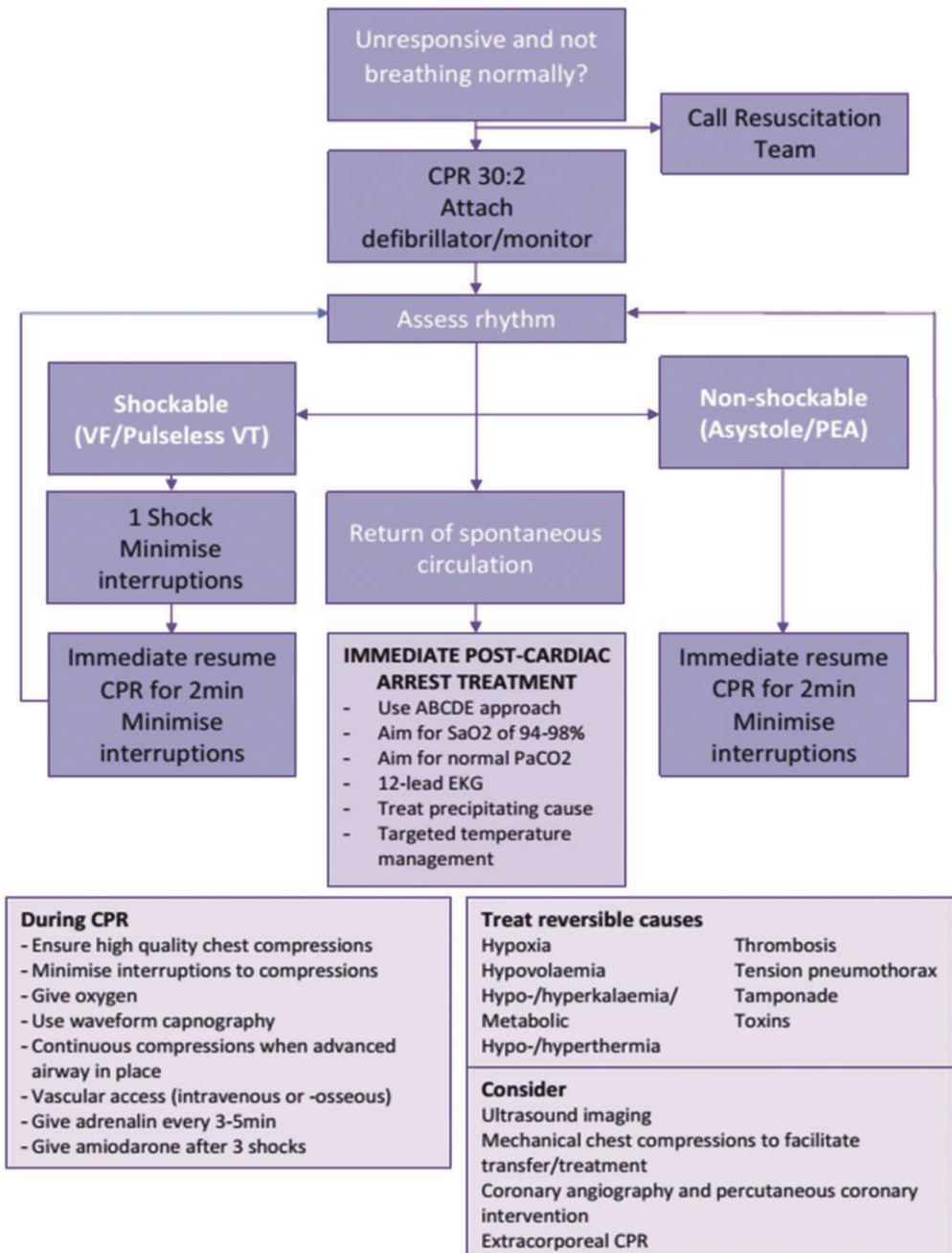


Figure 3. Advanced Life Support algorithm. Modified from ERC guidelines 2015.

2.2 Aetiology and Incidence of Cardiac Arrest

Ischaemic heart disease is the leading cause of death in the world (WHO 2016), including in Finland (Official Statistics of Finland (OSF) 2019). In 2017, diseases of the circulatory system explained 36 % and ischaemic heart diseases 25 % of all deaths in Finland in the population aged at least 65 years (OSF 2019).

In out-of-hospital cardiac arrest (OHCA) patients the most common initial rhythm is non-shockable, and the underlying reason for CA is a cardiac cause in approximately 20 % of the cases (Hiltunen 2012; Setälä 2017). In a study by Bergum et al. (2014), cardiac causes were behind 60 % of all the in-hospital cardiac arrest (IHCA) cases, and, of all the discharged patients, 30 % had a cardiac cause for their CA. Similar findings were published by Wallmuller (2012). Wallmuller reported that 63 % of the resuscitated patients had a cardiac aetiology and 15 % had a pulmonary aetiology for their CA.

Potentially aggravating factors or reversible causes for CA, for which specific treatment exists, must be considered during resuscitation attempts (Truhlář 2015). An easy to remember mnemonic “4H4T” (hypoxia, hypovolaemia, hypo-/hyperkalaemia, hypothermia, thrombosis (cardiac/pulmonary), tamponade cardiac, toxins, tension pneumothorax) can be effective when contemplating the underlying reason for CA in an emergency (Kloeck 1995 and 1997).

The incidence of EMS-treated OHCA for all rhythms in Europe is 38 per 100,000 people (Atwood 2005) and in Pirkanmaa area, Finland, 52 per 100,000 people per year (Setälä 2017). The incidence of IHCA in Europe varies in the range of 1–5 per 1000 admissions (Sandroni 2007) and corresponding number in the USA is 2.85 per 1000 hospital admissions (Kolte 2015).

2.2.1 Survival from Cardiac Arrest

Survival from IHCA is approximately 15 %, being slightly higher than survival from OHCA (Akintoye 2020; Doan 2020; Nolan 2014; Wallmuller 2012). Schlupe et al. (2018) published a systematic review article with meta-analysis, in which pooled one-year survival after IHCA was 13.4 %. Subgroup analysis revealed that patients with a cardiac reason for CA had higher survival rates than those with non-cardiac reasons, 39.3 % versus 10.7 %, respectively. Higher percentages of survival, up to 40 %, have been reported from hospitals with dedicated Medical Emergency Teams (MET) (Fredriksson 2006; Herlitz 2000). The prognosis for survival is better among

IHCA patients whose CA occurs in a monitored setting (intensive or intermediate care unit, emergency room) (Herlitz 2001a, Sandroni 2004). It also improves for patients who have witnessed CA with VF as the initial rhythm with a short time between the collapse and the arrival of the resuscitation team and have a short duration of CPR (Brady 2011; Cooper 2006; Huang 2002; Meaney 2010; Sandroni 2007).

2.2.2 Medical Emergency Team

The concept of medical emergency team or rapid response team (RRT) was created and implemented in Sydney, Australia in 1990. The main focus was to improve the detection of patient's vital function deterioration, prevent cardiac arrests and improve cardiac arrest victim's treatment and survival. (Lee 1995.) Since then implementation of METs/RRTs have spread worldwide. Depending on hospital policy, the team is comprised of 1-3 nurses or doctor and 1-3 nurses.

2.3 Quality of Cardiopulmonary Resuscitation

The quality of CPR performed by trained rescuers and also bystanders is related to the outcome of CA patients and has an impact on survival (Adielsson 2011; Gallagher 1995; Goharani 2019; Wik 1994). Deeper CCs are associated with higher rates of ROSC and with better defibrillation success (Edelson 2006; 2008; Li 2008; Ristagno 2007; Stiell 2012). Unfortunately, the quality of CPR is often suboptimal (Abella 2005; Abella 2007).

The quality of CCs can be classified with the following attributes: compression depth, compression rate, proportion of compressions with incomplete chest release, compression duty cycle, no-flow time, and ventilation rate (Perkins 2015a). Compression duty cycle comprises the whole compression interval starting from the beginning of the chest compression and ending when the chest is fully released. Optimal duty cycle is fifty percent describing the proportion of time used to compress the chest downward. No-flow time is defined as the time interval from the CA to start of CPR. Also, time intervals during CPR, when spontaneous circulation is not yet achieved and chest compressions are paused, are also included in no-flow time. All these attributes should be addressed when high-quality CCs are performed.

The use of real-time audio-visual feedback can improve the quality of CPR in both manikins and human resuscitations and in the hands of experienced and inexperienced users (Bobrow 2010; Havel 2010; Hostler 2011; Kim 2019; Kirkbright 2014; Wattenbarger 2019). The first generation of real-time audio-visual feedback devices use force signals and accelerometer to calculate the movement of the CC sensor enabling the estimation of the compression depth. The accelerometers can measure and record the above-mentioned CPR quality attributes in real time and also record the number of shocks delivered and the hands-off time before and after each shock. (Aase 2002; Losert 2007.)

2.3.1 Cardiopulmonary Resuscitation during Transportation

Refractory CA patients who fail to achieve ROSC at the scene and are transported to hospital with ongoing CPR have less chances of survival than patients who sustain ROSC before transportation (Gregers 2018; Zive 2011). Though CPR during ambulance or helicopter transportation is not customary at least in Europe, some limited patient groups, e.g. hypothermic patients, should be transported with continuous CPR (Truhlář 2015).

The quality of CPR can be hampered during transportation. A moving ambulance creates an unstable environment for the rescuers to perform CCs adequately and also puts rescuers at risk of an injury. The unstable environment can be one of the reasons why the variation in compression quality increases during ambulance transportation and also in the transition phase from the ambulance to hospital. (Cheskes 2017; Chung 2010; Roosa 2013.) In a study by Ødegaard (2009), the quality of CPR remained constant and was equal to the quality prior to transportation, but the rescuers failed to reach sufficient depth of compression both at the scene and during transportation. Skilled rescuers who are able to perform high-quality CPR at the scene still fail to maintain the quality while transporting the patient (Edelson 2006; Olasveengen 2008).

The audio-visual feedback devices mentioned above can improve the quality of CPR (Havel 2010; Hostler 2011; Kirkbright 2014), but the risk of injuries for the rescuers is not diminished. Mechanical chest compression devices may provide one way to improve the quality of CPR and facilitate the transport of a patient with ongoing CPR, while reducing the risk of injuries for the rescuer (Steen 2005).

Although the use of these mechanical devices can improve the quality of CPR, the effect on survival is not known (Perkins 2015b; Rubertsson 2014; Wik 2014). Nevertheless, in cases where the patient is transported with ongoing CPR, the use of mechanical chest compression devices should be considered (Truhlář 2015).

A limited number of countries also have access to extracorporeal CPR (ECPR). In ECPR venoarterial extracorporeal membrane oxygenation (VA-ECMO) technique is used to provide temporary mechanical support for the blood circulation and gas exchange (Rao 2018). ECPR can be used as a rescue therapy for patients with unsuccessful ALS resuscitation attempt and who are thought to benefit from specific interventions e.g. primary percutaneous coronary intervention (PPCI) or pulmonary thrombectomy (Kim 2016; Lamhaut 2017; Ortega-Deballon 2016). Especially patients with myocardial infarction as the CA cause could benefit from a rapid transfer with ongoing CPR or ECPR to a hospital with immediate facilities for PPCI (Azadi 2012; Wagner 2010). ECPR can also provide a way to transport organ donor candidates to hospital (Ortega-Deballon 2015).

It is important to bear in mind that futile resuscitation attempts waste emergency services resources and cause needless human suffering (Stub 2014). In cases where rescuers fail to achieve ROSC at the scene, CA is unwitnessed, initial rhythm is non-shockable and the patients age is over 65, the prognosis of survival is poor (Goto 2013; Morrison 2014). Rules for terminating resuscitative efforts and for avoiding groundless transports have been developed (Bonnin 1993; Morrison 2006; Ruygrok 2009; Setälä 2017). Ethical guidelines for ambulance personnel have also been established to help with the decision-making on starting or terminating resuscitation attempts when encountering OHCA patients (Åsgård 2012).

2.3.2 The Mattress Effect

When a resuscitation attempt is performed on compliant surface, the thrust of a CC compresses the chest, which also causes mattress displacement. Depending on the mattress, the deflection can be more than 10 mm. (Nishisaki 2009.) There are speculations on whether the mattress effect may at least partly explain the poor outcome of CPR (Edelson 2006; 2008; Kramer-Johansen 2006; Perkins 2003; Stiell 2012). With the use of a backboard, the effect of mattress displacement can be reduced (Cheng 2017; Nishisaki 2012). However, the quality of CPR is often below standard, even when backboards are used, and mattress effect is taken into

consideration. The placement of a backboard can also cause delays in the initiation of CCs. (Abella 2005; Abella 2007; Jäntti2009; Perkins 2015a.) Although audio-visual feedback devices can improve the quality of CPR, the majority of these devices cannot measure the bias in compression depth due to mattress effect and, therefore, can overestimate the depth of compression (Lin 2017; Nishisaki 2009; Noordergraaf 2009; Perkins 2009).

Manikin studies have confirmed that two feedback devices can be used to measure CC accurately without the risk of bias from the mattress effect (Nishisaki 2009; Oh 2012). Although manikins can simulate human properties well, humans have a large range of body weights and characteristics that cannot be mimicked by manikins; therefore, the results of those studies cannot be directly generalised to CPR attempts on humans.

2.4 Chest Compressions and Injuries

2.4.1 Risk Factors

Ever since the birth of modern CPR there have been suspicions of iatrogenic injuries related to CCs (Baringer 1961; Enarson 1976). Complications relating to CPR and especially to CCs can be divided into three groups: 1) injuries to the chest wall and fractures of the ribs and sternum; 2) injuries to the internal organs and great vessels in the chest cavity, including lacerations and ruptures of heart, lung, aorta and vena cava; and 3) injuries below the diaphragm: lacerations and ruptures of the liver, spleen and stomach. The first rib fractures caused by CCs were reported in 1961 (Baringer 1961). Although the composition of the chest makes it compliant and elastic, the force required to achieve 38 mm compression depth in an adult chest is approximately 320 newtons (N) (Tomlinson 2007). This translates to a maximum of 50 kg, depending on the acceleration of the downward movement. Interindividual properties of the patients such as stiffness of the chest, affects the force needed to reach a sufficient depth (Tomlinson 2007).

Females are more prone to sustaining CPR-related injuries than males (Krischer 1987; Black 2004; Kim 2013). The anatomical features of the female sternum, which is smaller and thinner than of males, increases the risk of iatrogenic sternum fractures during CPR (Rabl 1997). Baubin (1999), Black (2004) and Hashimoto (2007) have reported that females patients have 5 to 43 % more sternum fractures than male

patients. Rib fractures are also more frequent in female patients. This has been thought to be a result of the higher prevalence of osteoporosis in women than men. On the average, female patients are older than male patients at the time of resuscitation. (Perers 1999; Herlitz 2001b.)

Advanced age is associated with a higher incidence of rib and sternal fractures (Baubin 1999; Black 2004; Krischer 1987). Although no bone density analysis has been made in CA victims, the fractures can be assumed to be due to physiological changes in bone density and structure during aging.

The duration of CPR is an independent risk factor for injuries (Takayama 2018), but it has been suggested that the injuries occur within the first minutes of the beginning of the CCs (Baubin 1999). The use of mechanical chest compression devices are proven to cause more compression-related injuries than manual chest compression (Friberg 2019).

Although a large number of studies have analysed CPR-related injuries, none link the actual compression depth used during a CPR attempt to the injuries. It has been shown that the quality of CCs is often suboptimal (Abella 2005; Abella 2007; Perkins 2015b). Accordingly, it is impossible to analyse the possible association of the depth of CCs with the incidence of injuries.

2.4.2 Common Injuries

Fracture of the sternum and ribs are the most common injuries related to CCs (Beom 2017; Kashiwagi 2015; Kim 2011; Kim, 2013; Olds 2015; Pinto 2013). Hoke and Chamberlain (2004) reported the results of fifteen separate studies, and the incidences of rib fractures varied from 13 to 97 % and of sternal fractures from 1 to 43 %. The use of a mechanical chest compression device increases the risk of sternal or rib fractures (Friberg 2019). None of the fractures were life-threatening, but multiple rib fractures and a flail chest do indisputably affect recovery by impairing ventilation which, in turn, results in an increased number of lung infections.

2.4.3 Rare Injuries

Injuries of soft tissues and internal organs are more uncommon than rib cage fractures. Some soft tissue bruising and bleeding can result from a rib or sternal fracture. A systematic review and pooled analysis of CPR-associated injuries (Miller

et al. 2014) reported that the incidence of endo-, peri- or epicardial injury varies from 2-8.5 % in cases where standard CPR was performed. Myocardial- and epicardial haematomas can be caused directly by CCs without the presence of myocardial infarction. When the heart is pressed against the anterior chest wall and spinal column, haematomas or petechiae can occur particularly in the ventricular septa or posterior wall (Hashimoto 2007). Life-threatening pericardial effusions after the rupture of the myocardium are usually rare, but incidence as high as 8.4 % has been reported (Powner 1984, Krischer 1987, Patterson 1974). A rupture can happen spontaneously, but it can also be a direct result of CCs during CPR. Usually the rupture is located in the left ventricle; Takada et al. (2003) reported findings of 77 tamponade cases in which left ventricular ruptures were unrelated to cardiac massage and the pathological changes to the infarcted myocardium had instead caused the rupture.

Pulmonary injuries include pneumothorax in 2.1 %, pleural effusion or haemothorax in 3.9 % and pulmonary bone marrow or fat emboli in 21 % of the cases (Miller 2014). Lungs can be injured as a direct consequence of CCs, as a result of a broken rib (Hashimoto 2007). Pneumothorax can be caused by forceful artificial ventilation leading to increased pressure in the alveoli (Shulman 1987, Matsubara 1997). In a study by Beom et al. (2017), 6.3 % of the patients had life threatening injuries after CCs, including massive subcutaneous emphysema, haemoperitoneum, haemomediastinum, tension pneumothorax and pneumoperitoneum. These injuries were only seen after the implementation of the 2010 resuscitation guidelines. With the use of mechanical CCs devices, the risk of potentially life-threatening injuries increases. Friberg (2019) reported 10 % incidence of severe soft-tissue injuries when the LUCAS® Chest Compression System was used during CPR.

The incidence of hepatic ruptures varies from 0.8 to 4.3 %. They are usually caused by a dislocated rib fracture, and the incidence may be higher in patients whose liver is located higher than normal. (Hoke 2004; Hashimoto 2007; Meron 2007; Kouzu 2012.) Splenic ruptures occur in less than 1 % of the resuscitation attempts. They can be caused by dislocated rib fractures but may also be associated with the poor quality of CCs. (Subramani 2002; Hoke 2004; Olds 2015.)

Gastric mucosal lacerations in the lesser curvature are rare, with an incidence of 1 %. The lacerations are the result of excess inflation of the stomach due to bag-valve ventilation or improper intubation. CCs increase the risk for gastric lacerations when the stomach is inflated improperly. (Hashimoto 2007.)

Other rare injuries associated with CPR also include thoracic vertebral fractures (Azuma 1986; Goldberg 1988; Jeong 1975; Okel 1968), which are associated with osteoporosis, osteopenia, and kyphosis.

2.4.4 Detection of Injuries

There are several ways to detect post-resuscitation injuries. Imaging modalities, such as conventional chest X-rays, computed tomography (CT)-scan and ultrasound, are available for the survivors. The injuries of non-survivors, on the other hand, can be analysed in forensic or medical autopsies, depending on the protocol used. An autopsy is considered the best method to detect injuries, as some fractures might be left undetected in conventional chest X-rays (Lederer 2004). More detailed information is gathered using a CT-scan to detect injuries, especially, when detecting fractures (Kim 2011). CT-scans have been used to analyse injuries of trauma victims in the post-mortem phase (Hoey 2007; Sochor 2008; Scholing 2009) and provide a valuable method for detecting bone injuries and some soft tissue injuries in the post-resuscitation phase. However, some injuries may only be diagnosed in an autopsy (Smekal 2013).

2.5 Quality of Life after Cardiac Arrest

2.5.1 Quality of Life

The ability to function in daily living, health, self-awareness and satisfaction with life and socioeconomic factors are the four key elements that form the basis for quality of life (QoL) (Felce 1995). For the broad and subjective nature of QoL, it includes both positive and negative aspects of life (The WHOQOL Group 1998).

Since the 1980s, the term health-related quality of life (HRQoL) and its determinants have been used to comprise those aspects of overall QoL that can be clearly shown to affect either physical, mental or social components of health and well-being (Guyatt 1994; Gandek 2004; McHorney 1999; Selim 2009). QoL can be contemplated from two perspectives. Individual-level QoL includes one's perception of physical and mental health, such as health risks, conditions, functional status, social support, and socioeconomic status. Community-level QoL, which includes policies, practices and resources, influences perceptions of health in larger populations. (Kindig 2010.)

A number of different scales have been developed to measure QoL, many of which have been used to analyse QoL after CA (Brooks 1996; Gamper 2004; Hays 2006; Meaney 2013; The WHOQOL Group 1998; WHO 1993). The EuroQoL Group has developed a QoL questionnaire, EuroQoL (EQ-5D), which includes questions on five domains of everyday living (Brooks 1996). Those five dimensions – mobility, self-care, usual activities, pain/discomfort, and anxiety/depression – are graded no / some / major problems. From the answers to those questions, a simple score (EQIndex) is calculated. A score of 1.00 equates to full health and 0.00 to death in the EQIndex. The second part of the questionnaire is a self-rated visual analogue scale (VAS), ranging from 0 to 100, with 100 indicating the best possible overall health. (Brooks 1996; WHO 1993.) The questionnaire is validated by being answered also by the next of kin (Badia 1996 and 2001). In the EQIndex, perceptions on health and economic situations in different countries reflect national values. In a national health survey made by the National Institute for Health and Welfare in Finland in 2011, 66 % of men and 69 % of women in the age group 65–74 years graded their QoL as good. The corresponding numbers for the EQIndex were 0.81 and 0.77, respectively. A change of 0.05 points was considered significant. (Koskinen 2012.)

The EQ-5D has also been used to report the QoL of CA patients (Cronberg 2009; Kearney 2020; Kimmoun 2020; Tiainen 2018).

2.5.2 Quality of Life after Cardiac Arrest

Survival rates after CA are increasing slightly, but they continue to vary markedly from region to region (Schluep 2018, Wong 2014). Previous studies have reported factors that predict better chances for survival to hospital discharge and a better prognosis for a good QoL among OHCA patients. These factors include VF as the initial rhythm, a short delay to ROSC, a low number of comorbidities, age <65 years and the quality of care in the hospital where the patient is transported. (Atwood 2005; Fukuda 2014; Granja 2002; Hallstrom 2007; Kearney 2020; Ohlsson 2014; Rea 2004; van de Glind 2013; Väyrynen 2008.) Significant predicting factors are bystander CPR and EMS. Depending on the above factors, the chance of survival after OHCA varies from 2 to 49 %. (Bunch 2004; Fischer 1997; Fredriksson 2003.)

Better neurological and functional conditions at hospital discharge are associated with long-term survival (Pachys 2014). In older patients, age ≥ 67 years, those with chronic obstructive pulmonary disease (COPD), malignancy, congestive heart failure, chronic kidney disease, diabetes and cirrhosis were likely to have worse outcomes than CA patients in same age group without chronic disease (Stapleton 2014). In a study conducted on eight very long-term (17 years) CPR survivors, Anderson (2015) reported that the risk of dementia was higher than in the normal population and that CA had led to permanent cognitive impairment. Memory is reported to be predominately affected in CA survivors (Buanes 2015; Moulaert 2009). The cognitive impairment was comparable to early Alzheimer's dementia, but it was not reflected on EQIndex scores, mainly on EQ-VAS.

Despite a large number of influencing factors on survival and poor survival rates, QoL is often reported to be reasonably good after OHCA and IHCA (Granja 2002). It seems that most adult CA victims who survive retain independence after CA, but some patients have poor outcomes (Beesems 2014; de Vos 1999; Horsted 2007; Larsson 2014; Meaney 2013; Saner 2002; van Alem 2004; Wilson 2014). Impaired physical functions after CA are associated particularly with victims aged over 65 years (Bohm 2019).

As stated earlier, fewer comorbidities are associated with better survival rate and higher QoL. The burden of diseases can be calculated using the Charlson Comorbidity Index (Charlson 1987). In the index, different diseases are weighted

according to the adjusted risk of mortality or the resource used. Diseases with their associated weight categories are shown in Table 1.

Table 1. Diseases included in Charlson Comorbidity Index and the weight categories (Charlson 1987).

Weight category	Diseases
1	Myocardial infarction Congestive heart failure Peripheral vascular disease Cerebrovascular disease Dementia Chronic pulmonary disease Connective tissue disease Ulcer disease Mild liver disease Diabetes
2	Hemiplegia Moderate and severe renal disease Diabetes with end-organ damage Any tumour Leukaemia Lymphoma
3	Moderate and severe liver disease Metastatic tumour
6	AIDS

The total score is the sum of the weight results, with a score of 0 indicating no comorbidities. The Charlson index has been shown to predict hospital mortality in critically ill patients and one-year survival (Christensen 2011; D’Hoore 1993; Norena 2006; Poses 1996).

2.5.3 Targeted Temperature Management

In OHCA patients, the most common initial rhythm is non-shockable (Hiltunen 2012, Setälä 2017). When the underlying cause of cardiac arrest is due to cardiac

reasons, VF is seen as an initial rhythm (Skrifvars 2013). In 2003, the ILCOR recommended the use of mild hypothermia for unconscious adult patients presenting VF as an initial rhythm and who had sustained ROSC after OHCA (Nolan 2003). Following the implementation of therapeutic hypothermia (TH), numerous studies reported significantly improved Cerebral Performance Categories Scales (CPC, table 2.) at hospital discharge and better outcomes than in patient groups treated without TH (Bernard 2002; Callaway 2014; Hypothermia After Cardiac Arrest Study Group 2002; Oddo 2006; Sunde 2007). However, in a study by Bro-Jeppesen (2009), no significant improvement in survival, quality of life or cognitive status was detected at a long-term follow-up. An identical finding was made by Bohm (2019). In 2013, Nielsen et al. published an article comparing targeted temperature management at 33 °C versus 36 °C and found no benefits favouring the 33 °C target. Since then, many intensive care units (ICUs) have changed the protocol to 36 °C/36 h.

Table 2. Cerebral Performance Category (CPC) Scale

Outcome	CPC Category
Positive	CPC 1: Full recovery or mild disability
Outcomes	CPC 2: Moderate disability, but independent in activities of daily living
Negative	CPC 3: Severe disability, dependent in activities of daily living
Outcomes	CPC 4: Coma or persistent vegetative state
	CPC 5: Dead

2.5.4 Coronary intervention and Implantable Cardioverter-Defibrillators

Patients presenting with ST-segment elevation myocardial infarction (STEMI) after ROSC benefit from early coronary intervention (Callaway 2014; Scholz 2018). In patients with STEMI even shorter patient-specific door-to-balloon time has been consistently associated with lower mortality over time (Nallamotheu 2015; Scholz 2018). Revascularisation and implantation of Implantable Cardioverter-Defibrillators (ICDs) are thought to reduce long term mortality by arrhythmia management (Arawwawala 2007, Barakat 2019).

3 AIMS OF THE STUDY

The aims of this thesis were:

1. To investigate the aetiology of IHCA's on general wards and the possible association of the aetiology, subjective antecedent and preceding vital dysfunctions with short-term survival (I).
2. To investigate the quality of CPR as reflected by chest compressions using real-time automated feedback devices during CPR on various surfaces and during ambulance transportation (II, III), and a possible association between objectively measured compression depth and CPR-related thoracic and abdominal injuries (IV).
3. To report on cardiac arrest patients' QoL six months after successful resuscitation and compare it with their QoL prior to resuscitation and analyse the possible factors influencing better outcomes (V).

4 MATERIALS AND METHODS

4.1 Study Settings

The Pirkanmaa Hospital District is a joint municipal authority of 23 municipalities. The hospitals located in the area are Tampere University Hospital (Tays), Vammala Regional Hospital and Valkeakoski Regional Hospital. Tays is a tertiary referral centre with 600 acute-care beds for a base population of 1,200,000. Yearly patient admissions are approximately 92,000, and 370,000 outpatients receive treatment every year. The incidence of sudden IHCAs was approximately 2.2/1000 hospital admissions annually, during the period 2009–2011.

The mixed ICU at Tays has 22 beds, 12 of which are primarily reserved for critically ill patients. The rest of the beds serve as a high dependency unit that provides special monitoring and treatment for patients with single organ dysfunction.

As a part of the ICU's daily function in Tays, the MET (medical emergency team) is designed to facilitate early recognition of patients at risk of clinical deterioration and also to take care of sudden CA victims' resuscitation attempts. The MET consists of two ICU nurses and an intensivist on-call. In 2008, the MET was piloted and, in 2009, implemented to cover the whole hospital. As a part of the MET's operation, quality data from resuscitations attempts have been routinely collected since 2008 for education and research purposes.

The Tampere Rescue Region Department has 22 operational areas in Pirkanmaa, Finland. The department is divided into three areas of responsibility: accident prevention and development, fire and rescue services and emergency medical services. The fire and rescue department and EMS responds to approx. 60 000 calls/year. All the ambulances operate on care-level/advanced life support-level. Care-level ambulances are equipped to start more complex care for the patient and protect vital functions during transportation. Care-level ambulances respond to CA calls together with the Finnish Helicopter Emergency Medical Services (FinnHEMS), a physician-staffed HEMS helicopter.

4.2 Data Collection

All the studies were performed with the approval of the Pirkanmaa Hospital District Science Center and the Ethics Committee of Tampere University Hospital (Approval no: R08116).

Authorisation to analyse forensic autopsy findings was granted from the National Institute for Health and Welfare and Regional State Administrative Agencies (I, IV).

In studies I, II, III and IV, the quality of CPR was monitored, and quality data was stored using HeartStart MRx defibrillators (Philips Professional Healthcare Amsterdam, Netherlands). Defibrillators were also equipped with accelerometers with a CPR-quality (Q-CPR, Laerdal Medical AS, Stavanger, Norway) analysis feature. The accelerometers are capable of recording and measuring CPR-quality parameters, such as CC depth and rate and the compression duty cycle by compression-to-compression and compressions with an incomplete chest release. They also record the hands-off time before and after each shock and the number of shocks delivered per patient and calculate the actual chest compressions performed per minute and the time without CCs (no-flow time).

4.2.1 Aetiology of In-Hospital Cardiac Arrest on General Wards

During the study period of 1 January 2009–31 December 2011, the MET responded to a total number of 381 resuscitation calls. All the resuscitation attempts were screened, and comorbidities, patient histories, initial rhythm, treatment details, medical and forensic autopsy records, and cause of CA in survivors were retrieved from the medical files. Patients not matching the inclusion criteria were excluded from the study. The total number of patients in the final cohort was 279 (Fig. 4.).

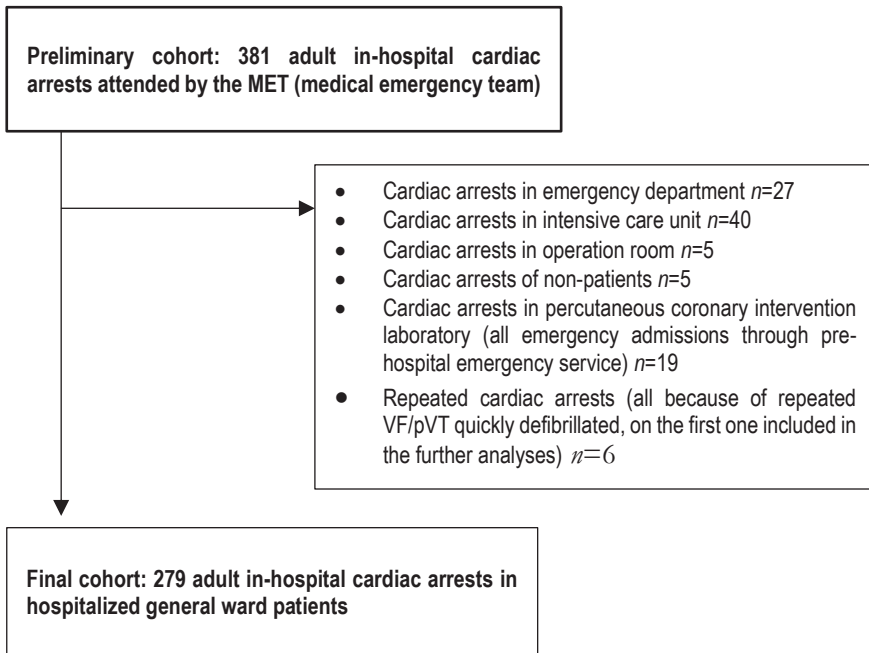


Figure 4. Final cohort of 279 IHCA patients. (figure modified from Aetiology of in-hospital cardiac arrest on general wards. Resuscitation 2016; 107:19-24).

4.2.2 The Quality of Manual Chest Compressions during Transport – Effect of the Mattress Assessed by Dual Accelerometers

In this non-randomised, prospective manikin study, 24 paramedics from the Tampere Regional Rescue Department participated in the study and performed CPR on a Resusci Anne® Manikin (Laerdal Medical AS, Stavanger, Norway), first without and then with the feedback device in a moving ambulance. Only the quality of CCs was recorded; ventilation and drug administration were excluded from this study.

Two accelerometers and two HeartStart MRx defibrillators (Philips Professional Healthcare, Amsterdam, Netherlands) were used to record the parameters related to the quality of the CC and the mattress effects. The participants performed standard CPR, according to European Resuscitation Council (ERC) 2010 Resuscitation guidelines. Each pair of paramedics acted as their own controls. In the non-feedback phase, the audio-visual feedback was enabled. In the feedback phase, audio-visual feedback was applied and correct use of the devices was revised. Figure 5 shows the use of dual accelerometers recording CC depth (Acc. 1) and stretcher deflection (Acc. 2). Accelerometer 1, on the midsternal area, measured the compression of the chest, mattress and stretcher together. Accelerometer 2 measured the deflection of the mattress and the stretcher only. Both accelerometers were connected to separate defibrillators.

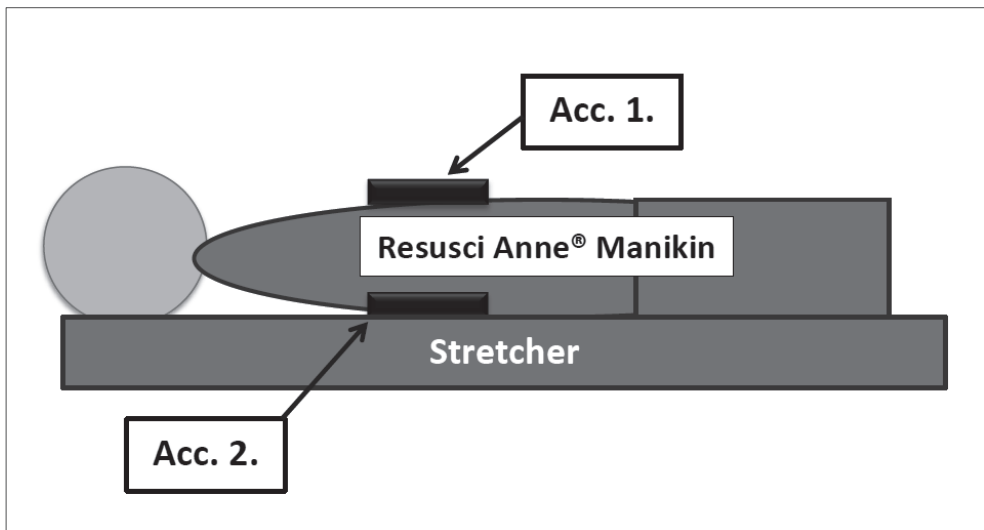


Figure 5. Location of the two accelerometers during the chest compressions during transport.

Two 10-min laps per pair of paramedics were driven on a public road. The driving speed was 40–60 km/h, depending on the speed limits. Each pair performed CPR without feedback (control) during the first lap and with feedback (intervention) during the second lap. The CCs were performed standing beside the manikin.

Windows-based Q-CPR Review software (v2.1.0.0. Laerdal Medical AS, Stavanger, Norway) was used to analyse the data. Before analysis, resuscitation sessions were divided into 30 s fractions/epochs. The compression rate, mean chest compression depth (mm), no-flow fraction and incomplete chest release were analysed from the data of accelerometer 1. The mattress and stretcher deflection was analysed using the data of accelerometer 2. The real compression depth was calculated individually as the remainder of accelerometer 1 minus accelerometer 2.

4.2.3 Effect of Mattress and Bed Frame Deflection on Real Chest Compression Depth Measured with Two Cardiopulmonary Resuscitation Sensors

This prospective study was conducted at Tays between 1 August 2011 and 30 September 2012. All adult IHCA patients were considered eligible for inclusion. In this study, two accelerometers were used to calculate real compression depth. The upper accelerometer was placed on the patient's chest underneath the rescuer's hands. The upper accelerometer guided CPR and collected data. The lower accelerometer was pre-attached to the backboard and used during the resuscitation attempt to collect data about mattress and bed-frame deflection. Figure 6 shows the

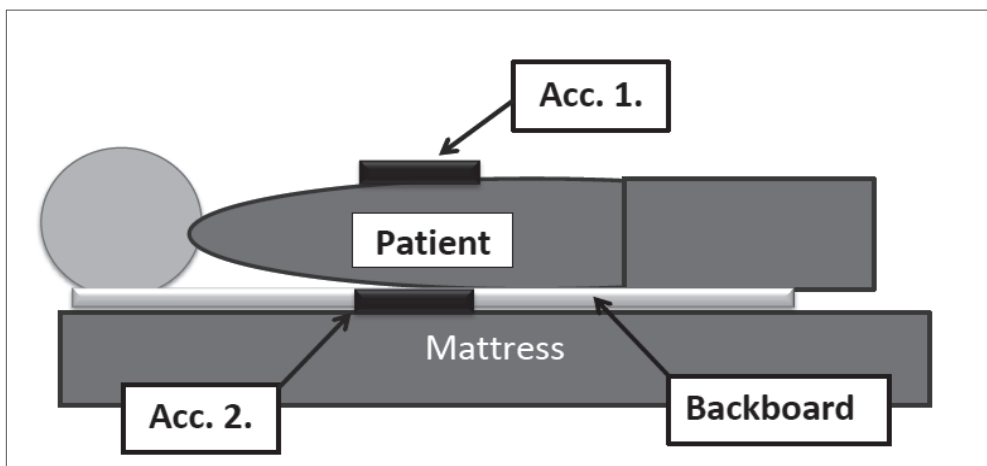


Figure 6. Location of the two accelerometers during the resuscitation.

placement of the two accelerometers and backboard during the resuscitation attempt.

4.2.4 Effect of Depth of Chest Compression on the Likelihood of Complications in Cardiac Arrest Patients

All adult patients resuscitated by the MET in Tays from 1 January 2009 to 31 December 2011 were considered for inclusion in the study. The final study population included patients whose resuscitation quality data (peak compression depth, compression depth, episode length, peak force and number of compressions per episode) were successfully measured with HeartStart MRx defibrillator (Philips Professional Healthcare, Amsterdam, Netherlands) and stored on a memory card for analysis purposes and whose chest radiography or chest/upper abdomen CT-scan was performed during post-resuscitation care. Patients with a proved unsuccessful resuscitation attempt were autopsied, and the findings were correlated with the quality details of the CPR.

CC-related injuries were analysed retrospectively from the forensic and medical autopsy records, CT-scan, and chest radiographies. One radiologist analysed patients' injuries by re-evaluating CT-scans and chest X-rays retrospectively, blinded to resuscitation quality data. Because trauma victims were excluded from the study, injuries interpreted to have been caused by CPR were rib and sternal fractures, haematomas (anterior mediastinal or associated with rib fractures), pneumo- or haemothorax, laceration, bruising or contusion of lung and heart, injuries to aorta or great veins and laceration/rupture of liver, stomach or spleen. Prior medical histories (diabetes mellitus, chronic renal failure, hyperparathyroidism, osteoporosis and rheumatoid arthritis, as well as long-term use of corticosteroids (inhaled or oral) and the consumption of alcohol or tobacco), body mass index (BMI) and age were obtained from each patient's medical records.

4.2.5 Effect of the Quality of Life before Cardiac Arrest to the Outcome Six Months after Resuscitation

In this retrospective observational study, all adult patients admitted to ICU after successful resuscitation from IHCA or OHCA from 1 January 2009 to 31 December 2011 were screened. Patients that survived and were living six months after the CA

were sent the EQ-5D questionnaire. Patients that answered the follow-up EQ-5D questionnaire constituted the study population.

Data from the EQ-5D questionnaire were combined with the EQ-5D questionnaire results prior to the CA, which is routinely used when a patient is admitted to ICU. From the patient file, prior medical histories, cause of resuscitation, initial rhythm, return of spontaneous circulation, if TH was used, possible procedures performed, (primary) percutaneous coronary intervention, coronary artery bypass surgery or implantable cardioverter-defibrillator/cardiac pacemakers implanted were collected retrospectively from patients' medical files. The Charlson Comorbidity Index (CCI) and estimated ten years' survival percentage were calculated using the data from the medical files.

Characteristics of the studies I-V are described in Table 3.

Table 3. Characteristics of the studies I-V.

Study	Design	Conduct time	Main objectives	Cohort
I	Retrospective, observational	1 st Jan 2009 – 31 st Dec 2011	Aetiology of cardiac arrest in general wards	279
II	Non-randomised, prospective mannequin	27 th – 28 th Aug 2011	Quality of manual chest compressions during transportation	24
III	Prospective	1 st Aug 2011 – 31 st Sep 2012	Effect of mattress and bed deflection on real compression depth	10
IV	Observational	1 st Jan 2009 – 31 st Dec 2011	Injuries related to chest compressions	170
V	Retrospective, observational	1 st Jan 2009 – 31 st Dec 2011	Quality of life 6 months after cardiac arrest	55

4.3 Statistical Methods

For all the studies, IBM SPSS Statistics for Windows (SPSS Version 22.0. Armonk, NY: IBM Corp.) was used to perform statistical analyses. Two-sided $p < 0.05$ was considered statistically significant, and 95 % confidence intervals were reported where appropriate.

(I) The Mann–Whitney U test, χ^2 test, Fisher’s exact test and Student’s t-test were used for comparisons between the groups, as appropriate. The Hosmer–Lemeshow test was conducted to report the model’s goodness of fit, and a multivariate logistic regression was applied with the ‘enter’ model.

(II) Mixed model analysis of variance (ANOVA) was used for the analysis of the compression rate, compression depth and real compression depth using the paramedic as a random factor and the feedback device as fixed factor. Comparisons of continuous data were performed with a Mann–Whitney U test and an independent samples t-test. Binomial variables were analysed with a χ^2 test to compare the overall effect of the feedback device.

(III) Differences between the groups were analysed using a Kruskal–Wallis test for continuous data or χ^2 test and Student’s t-test, as appropriate.

(IV) Binomial variables were analysed with a χ^2 test and comparisons of continuous data were performed with independent samples t-tests or Mann–Whitney U tests, as appropriate.

(V) Independent sample t-tests and Mann–Whitney U tests were used for comparison of continuous data. Binomial variables were analysed with a χ^2 test. The EQIndex after CA was dichotomised from 0.885 into two equal-sized groups. Forward stepwise binary logistic regression was used to explain a higher post-resuscitation EQIndex using the initial rhythm (VF vs. pulseless electrical activity (PEA)/asystole (ASY)), ROSC (min), CCI, (P)PCI/Coronary Artery Bypass Grafting (CABG), TH, age and EQIndex before the CA, as explanatory variables.

The data are presented as medians with interquartiles [Q1, Q3], means and standard deviations (SD) or percentages and numbers of patients, as appropriate. In sub-study V, the results for the binary logistic regression analyses are shown as an odds ratio (OR) and 95 % confidence interval (95 % CI).

5 RESULTS

5.1 Aetiology of In-Hospital Cardiac Arrest on General Wards

Altogether 279 in-hospital patients resuscitated by the MET were included in this study. 185 (66 %) were male, the median age was 72 (64, 80) years, and the mean age adjusted CCI was 5.0 ± 2.6 . ROSC was achieved in 140 (50 %) cases, and the primary rhythm was shockable (pVT/VF) in 42 (15 %) patients. 114 (41 %) patients survived the first 24 h, and 53 (19 %) patients were alive after six months.

In 126 (45 %) cases, the cause for IHCA was clinically assessed by the consultant in charge of the patient's care. In 30 of these cases, ROSC was not achieved; therefore, no further clinical or laboratory tests were conducted. For 153 (55 %) patients, an autopsy was conducted, comprising 84 forensic and 69 medical autopsies.

Cardiac aetiology was the reason for 141 (51 %) CAs, and, in these cases, acute myocardial infarction (AMI) was the most common cause of IHCA. In the non-cardiac aetiology group, infections, especially pneumonia, were the most common cause. Aetiologies of the CAs are shown in Table 4.

Positive MET activation criteria 20–720 min before the CA event were reported in 117 (42 %) patients. In the 'cardiac' cohort, 66 (47 %) patients had subjective antecedents, whilst the corresponding number was 44 (32 %) in the 'non-cardiac' cohort. Only one (0.7 %) patient in 'non-cardiac' group suffered from chest pain, compared to 15 (11 %) in the 'cardiac' group ($p < 0.001$). Differences between antecedents in the 'cardiac' or 'non-cardiac' cohort are shown in Table 5.

Monitored or witnessed CA ($p=0.024$), shockable primary rhythm ($p<0.001$), and lower age-adjusted CCI ($p=0.041$) were independently associated with 180-day survival. Cardiac aetiology and antecedent-free event had no association.

Table 4. Aetiologies of in-hospital cardiac arrest (Table modified from Aetiology of in-hospital cardiac arrest on general wards. Resuscitation 2016; 107:19-24).

Cardiac reason for IHCA	n=141	Non-cardiac reason for IHCA	n=138
Acute myocardial infarction	73	Pulmonary embolism	12
Myocardial ischaemia (no acute infarction)	26 ^a	Infection	
Cardiac tamponade	5	Pneumonia	39
Congestive heart failure	16	Peritonitis	11
Complication after invasive cardiac intervention	9	Urogenital infection	2
Other		Erysipelas	1
Dilated cardiomyopathy	2	Pancreatitis	3
Cardiac amyloidosis	2	Cholecystitis	2
Cor pulmonale	1	Sepsis, not further specified	6
Atrial fibrillation	1	Cirrhosis	3
Perimyocarditis	1	Renal insufficiency	2
Aortic stenosis	2	Exsanguination	
Aortic regurgitation	1	Gastrointestinal tract	10
Mitral regurgitation	1	Traumatic	3
Ascending aortic dissection	1	Airway	1
		Iatrogenic	2
		Cerebral ischaemia	4
		Anaphylaxis	2
		Hyperkalaemia	2
		Hyponatremia	2
		Hematologic malignancy	2
		Malignant solid tumour	7
		Mechanical airway obstruction	7
		Vasovagal collapse	1
		Acute mesenteric ischemia	1
		Overdose of opioids/benzodiazepines	2
		Hypoxia due to chronic lung disease	4
		Reason unclear	7

Data are presented as numbers

^aIn one case ischaemia was provoked by low haematocrit

Table 5. Comparison of antecedents to IHCA related to cardiac vs. non-cardiac aetiology (Table modified from Aetiology of in-hospital cardiac arrest on general wards. Resuscitation 2016; 107:19-24).

Documented objective MET activation criteria (20–720 min before the IHCA)	IHCA due to cardiac aetiology (n= 141)	IHCA due to non-cardiac aetiology (n= 138)	p-value
Respiratory rate (<5 or >24/min)	13 (9.2)	17 (12)	0.403
Peripheral arteriolar O2 saturation (<90 %)	29 (21)	30 (22)	0.811
Heart rate (<40 or >140/min)	12 (8.5)	18 (13)	0.222
Systolic blood pressure (<90 mmHg)	16 (11)	8 (5.8)	0.222
Any objective criteria	56 (40)	61 (44)	0.488
Multiple objective criteria	13 (9.2)	11 (8.0)	0.710

Recorded subjective antecedents (20–720 min before the IHCA)	IHCA due to cardiac aetiology (n= 141)	IHCA due to non-cardiac aetiology (n= 138)	p-value
Respiratory distress	42 (30)	31 (23)	0.164
Chest pain	15 (11)	1 (0.7)	<0.001
Arrhythmias	2 (1.4)	1 (0.7)	0.574
Upper abdominal pain	3 (2.1)	4 (2.9)	0.681
Back pain	2 (1.4)	2 (1.4)	0.983
Cold sweat	5 (3.5)	5 (3.6)	0.972
Decrease in the level of consciousness	8 (5.7)	16 (12)	0.078
Any subjective antecedent	66 (47)	44 (32)	0.022
Multiple subjective antecedents	11 (7.8)	12 (8.7)	0.786

Data are presented as numbers (percentages).

IHCA, in-hospital cardiac arrest; MET, medical emergency team.

5.2 The Quality of Manual Chest Compressions during Transport – Effect of the Mattress Assessed by Dual Accelerometers

The total number of 30-s fractions/epochs included in the analyses was 507: 252 without feedback and 255 with real-time audio-visual feedback. Details of CC depths in the control and feedback phases are presented in Table 6.

Table 6. Quality of CPR of a resuscitation manikin in a moving ambulance. Quality was assessed during the control phase without any feedback of the quality of CPR and during real-time audiovisual feedback (Table modified from The quality of manual chest compressions during transport - effect of the mattress assessed by dual accelerometers. Acta Anaesthesiol Scand 2014;58:323-8.)

	Study population (n = 24)		
	Real-time audiovisual feedback	Control	p-value
Mean compression depth (mm)	56 (5)	51 (10)	<0.001
Mattress deflection (mm)	12 (2)	11 (3)	<0.001
Real compression depth (mm)	44 (5)	41 (8)	<0.001
Compression rate (/min)	103 (5)	104 (20)	0.55
No-flow fraction	0.10 (0.05, 0.15)	0.09 (0.04, 0.13)	0.82

The data are given as mean (SD) or median (Q₁, Q₃).

The percentage of 30-s fractions/epochs with mean a compression depth \geq 50 mm increased from 50 to 89 % when the control phase was switched to feedback phase ($p < 0.001$), and the percentage of 30-s fractions/epochs with a mean compression rate of 100–120/min increased from 40 to 61 % ($p < 0.001$).

When analysed per paramedic compression, depth during the feedback phase was statistically deeper than during the control phase ($p = 0.003$), as shown in Figure 7.

When the quality of CPR was analysed by two accelerometers, the real compression was 41 (8) mm in control phase vs. 44 (5) mm in the feedback phase ($p < 0.001$). The effect of the mattress and stretcher to the compression depth and the real compression depth per paramedic and can be seen from Figure 8.

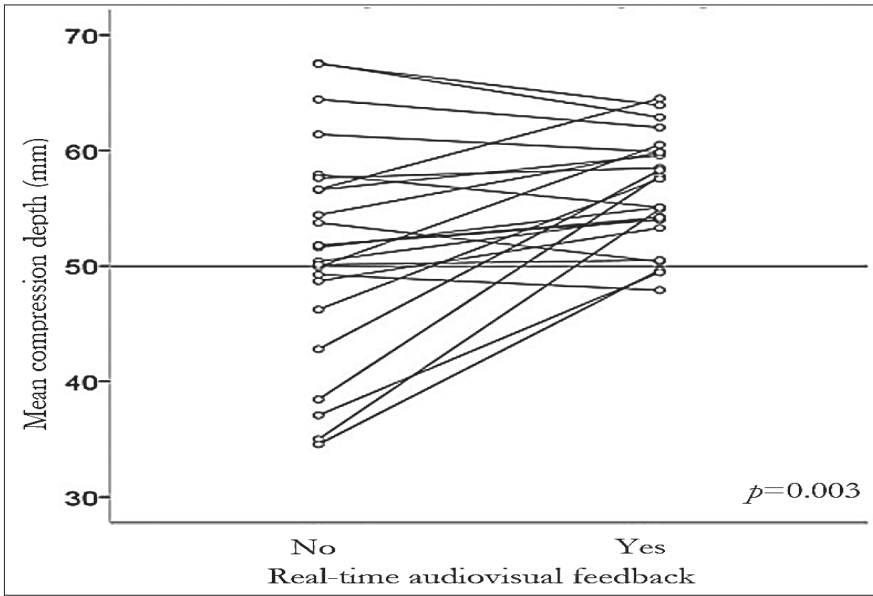


Figure 7. Mean compression depth as achieved by 24 paramedics without (control) and with real-time automated feedback. Each line represents an individual paramedic (Figure modified from The quality of manual chest compressions during transport - effect of the mattress assessed by dual accelerometers. *Acta Anaesthesiol Scand* 2014;58:323-8.).

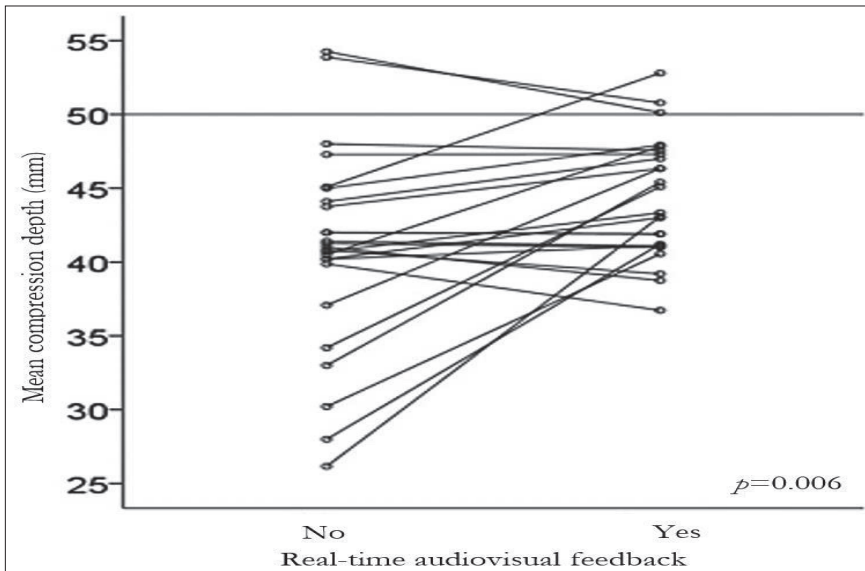


Figure 8. Real depth when the mattress and stretcher effect is taken into account. Each line represents an individual paramedic (Figure modified from The quality of manual chest compressions during transport - effect of the mattress assessed by dual accelerometers. *Acta Anaesthesiol Scand* 2014;58:323-8.).

5.3 Effect of Mattress and Bed Frame Deflection on Real Chest Compression Depth Measured with Two Cardiopulmonary Resuscitation Sensors

Ten patients (out of 74 resuscitated during the study period) were resuscitated with the dual accelerometer system. Three CPR attempts were performed on ICU beds, three on emergency room (ER) stretchers and four on a standard hospital bed (HB). A total of 10,868 CCs (246–6398 per patient) were analysed using the dual accelerometer system. The results are summarised in Table 7.

Table 7. Effect of bed and mattress type on chest compression depth. Compression depths, total and real, were measured with dual accelerometer system (Table modified from Effect of mattress and bed frame deflection on real chest compression depth measured with two CPR sensors. Resuscitation 2014;85:840-3).

	HB (n=1464)	ER (n=7311)	ICU (n=2093)
Total depth (mm)	66 (11)	68 (9)	59 (6)
Mattress/bed deflection effect (mm)	12.8 (4)	12.4 (4)	14.1 (3)
Real CC depth (mm)	53 (9)	55 (7)	44 (6)
Mattress/bed contribution on CC depth (%)	20 (5)	18 (5)	24 (5)
Proportion of CC's with depth > 50 mm (%)	94	98	91
Proportion of CC's with real depth > 50 mm (%)	64*	76*	17*

The data are given as mean (SD) or percentage.

HB, standard hospital bed with gel mattress: Hospital bed Carena (Merivaara Oy, Lahti, Finland); mattress type: Mattress MediForm Safe (Merivaara Oy, Lahti, Finland).

ER, emergency room stretcher with standard mattress: Trolley Emergo (Merivaara Oy, Lahti, Finland); mattress type: Standard gel mattress (Merivaara Oy, Lahti, Finland)

ICU, intensive care unit bed with air mattress: Hospital bed Carena (Merivaara Oy, Lahti, Finland); mattress type: Air Mattress, Quattro acute (Talley Medical, Hampshire, UK).

* $p < 0.001$ for difference compared to fraction of CC's with depth >50 mm without compensation for mattress/bed frame deflection.

The proportion of CCs on HB with adequate depth decreased from 94 to 64 % after compensation ($p < 0.001$). The corresponding for ER beds were 98 % and 76 % ($p < 0.001$) and, for ICU beds, 91 % and 17 % ($p < 0.001$).

5.4 Deeper Chest Compression - More Complications for Cardiac Arrest Patients?

During the study period, a total of 486 sudden CAs occurred in Tays. Of these patients, 370 were resuscitated by the MET, and 170 sudden cardiac arrest (SCA) patients were included in the study. 65 % were male. Of all the included patients, 32 % (n = 54) had sustained injuries, of which 74 % were male. When the injuries were analysed by year, the incidence of injuries was 25 % in 2009, 32% in 2010 and 40 % in 2011, ($p = 0.21$). In patients subjected to forensic autopsy, the incidence of injuries was 30 %, 42 % and 64 % in 2009, 2010 and 2011, respectively ($p = 0.03$). The percentage of short-term or immediate survival was not affected by a greater number of CPR-related injuries when analysed on a yearly basis.

5.4.1 Types of Injuries

Injuries are presented in Table 8.

Table 8. Injuries associated with chest compressions (Table modified from Deeper chest compression - more complications for cardiac arrest patients? Resuscitation 2013;84:760-5).

	All patients, n=170, n (%)	Male, n=110 (65) n (%)	Female, n=60(35) n (%)
Thorax			
Rib fracture	41/153 (26.8)	30/97 (30.9)	11/56 (19.6)
Single		7	3
Multiple		23	8
Sternal fracture	16/153 (10.5)	11/97 (11.3)	5/56 (8.9)
Hematoma - Rib fractures	11/41 (26.8)	7/80 (8.8)	4/52 (7.7)
Mediastinal haemorrhage	1 (0.8)	0	1/49 (2.0)
Pneumothorax	2/168 (1.2)	2/110 (1.8)	0
Haemothorax	0	0	0
Lung			
Contusion - Lung	1/134 (0.7)	0	1/51 (2.0)
Heart and great vessels			
Hematoma/Rupture - Heart	8/127 (6.3)	6/80 (7.5)	2/47 (4.3)
Posterior hematoma	3	2	1
Rupture	5	4	1
Great vessels	2/126 (1.6)	2/79 (2.5)	0
Abdomen			
Liver rupture	0	0	0
Spleen rupture	1/125 (0.8)	1/78 (1.3)	0
Gastric rupture	1/125 (0.8)	0	1/47 (2.1)

The injuries are presented as number and percentage of patients. Number of patients in each injury category varies based on injury detection method.

5.4.2 Compression Depth and Injuries

In the three-year period, the mean compression depth in patients without injuries was 52 mm compared to 56 mm in patients who sustained CPR-related injuries ($p = 0.04$). There was an increase in the frequency of injuries of 28 %, 27 % and 49 % when the mean compression depth was divided into three categories (<50 mm, 50–60 mm and >60 mm), respectively ($p = 0.06$).

The resuscitation guidelines changed in 2011. After the guidelines' implementation, the mean compression depth in the group of patients without injuries was 55 mm compared to 63 mm in patients with injuries ($p = 0.002$). The association between compression depth and injuries on a yearly basis are shown in Figures 9 and 10.

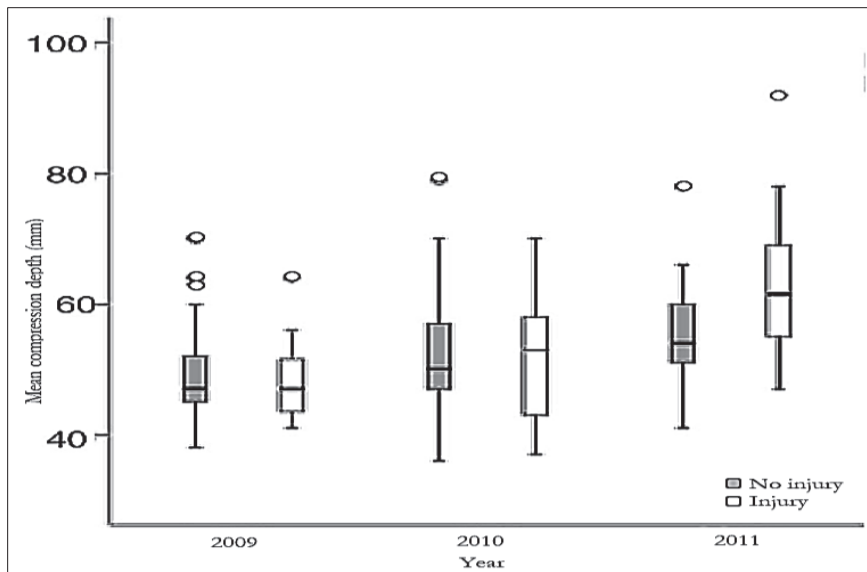


Figure 9. Mean compression depth by year and in injury and non-injury categories (Figure is modified from Deeper chest compression - more complications for cardiac arrest patients? Resuscitation 2013;84:760-5).

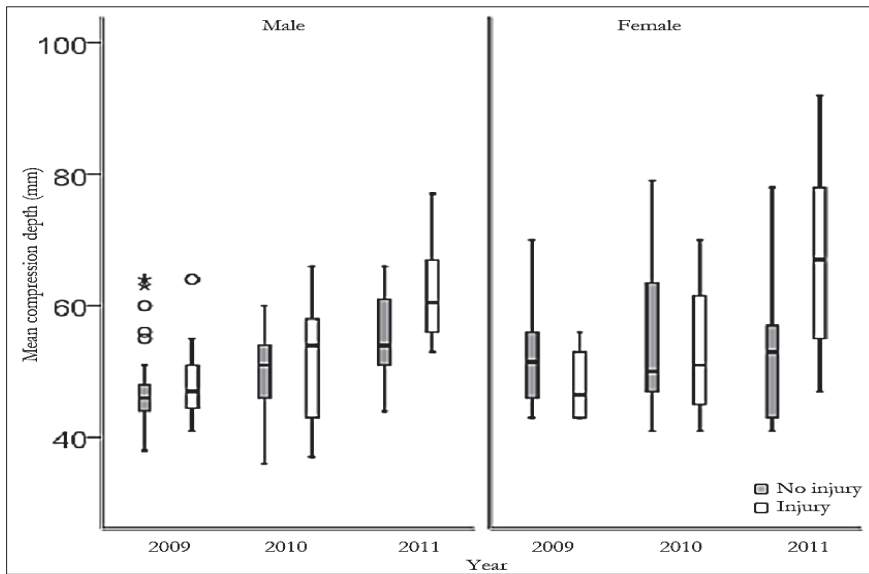


Figure 10. Mean compression depth yearly between injured and non-injured male and female patients (Figure is modified from Deeper chest compression - more complications for cardiac arrest patients? Resuscitation 2013;84:760-5).

5.5 Quality of Life after Cardiac Arrest

During the study period, a total of 222 patients were admitted to the ICU for post-resuscitation care. After six months, 79 of 222 (36 %) patients were alive, and 55 of 79 (70 %) made a post-discharge follow-up visit to the ICU clinic or replied by mail to the EQ-5D questionnaire. Characteristics of the patients are shown in Table 9.

Table 9. Characteristics of the patients (table modified from Good quality of life before cardiac arrest predicts good quality of life after resuscitation. *Acta Anaesthesiol Scand* 2018;62:515-21).

Variables	Study population n=55 (%)	IHCA n=20 (36)	OHCA n=35 (64)
Age	68 [60, 77]	72 [64, 80]	65 [60, 73]
Gender, male (%)	42 (76)	14 (70)	28 (80)
CCI (%)			
Index value 0	18 (33)	4 (20)	14 (40)
Index value 1-2	26 (48)	9 (45)	17 (49)
Index value ≥	11 (19)	7 (35)	2 (11)
Estimated 10y survival (%)	56 (33)	41 (36)	64 (29)
EQIndex ^a	0.89 [0.63, 1]	0.85 [0.63, 0.92]	0.89 [0.72, 1]
EQIndex ^b	0.89 [0.62, 1]	0.85 [0.62, 0.92]	0.89 [0.71, 1]
ROSC, min	13 [8.0, 25.0]	7.5 [5.3, 12.3]	19.0 [11.0, 31.0]
TH (%)	28 (51)	5 (25)	23 (66)
Revascularisation ^e (%)	15 (27)	1 (5)	14 (40)
ICD/PAMA (%)	17 (31)	3 (15)	14 (40)
Cause of CA			
Cardiac origin (%)	37 (67)	8 (40)	29 (83)
Non-cardiac origin (%)	18 (33)	12 (60)	6 (17)
Initial rhythm			
Shockable rhythm (%)	36 (65)	6 (30)	30 (86)
Non-shockable rhythm (%)	19 (35)	14 (70)	5 (14)

The data are presented as medians [Interquartiles] or as numbers and percentages of proportions. CCI: Charlson Comorbidity Index, EQIndex^a: Quality of Life Index before cardiac arrest, EQIndex^b: Quality of Life Index after cardiac arrest, ROSC: Return of Spontaneous Circulation, TH: Therapeutic Hypothermia, ICD/PAMA: Implantable Cardioverter-Defibrillator/Pacemaker, CA: Cardiac Arrest

The EQIndex prior to CA within the whole study population was 0.89 (0.63, 1) and it remained 0.89 (0.62, 1) afterwards as well ($p = 0.75$). Patients with a non-cardiac reason for CA scored 0.11 points higher on the EQIndex after CA, but the difference was not statistically significant.

6 DISCUSSION

6.1 Aetiology of Cardiac Arrest

Half of the cardiac arrests on general wards were due to cardiac reasons. Majority of these cardiac arrest patients suffered from acute myocardial infarction or ischaemia, which accounted for 35 % of all the arrests. Especially this patient population had preceding subjective antecedents, such as chest pain. Second largest group for cardiac arrest was congestive heart failure. Similar findings, concerning the percentage of cardiac origin, were published by Bergum (2014) and Wallmuller (2102). Even though cardiac origin was the main reason for cardiac arrest, astonishingly small number of patients (15 %) had shockable primary rhythm.

In cardiac arrests, where the reason was non-cardiac, the main aetiology was pneumonia. Second and third most common reason were exsanguination and pulmonary embolism. In this patient group preceding antecedents were less common and with the exception of three patients, all other patients had non-shockable initial rhythm.

Current resuscitation guidelines emphasises that alongside high-quality CPR it is important to treat possible underlying cause. `4T4H`-rule can be used as mnemonic (Soar 2015). In this study, aetiology of 112 cardiac arrest patients could be classified using the `4T4H`-rule stating the importance of `4T4H`-rule as a part of ALS algorithm.

Two thirds of the cardiac arrests in this study were witnessed/observed. Witnessed/observed cardiac arrests has been associated with better outcome (Brady 2011) and similar findings were observed in this study. Also, in this study low comorbidity and shockable primary rhythm were independently associated with better 6-months survival, even when adjusted for gender and aetiology and, for the first time, for preceding derangements.

6.2 Quality of Cardiopulmonary Resuscitation

Based on the results, the quality of CPR, especially that of CCs, significantly improved in a moving ambulance when an audio-visual feedback device was in use. It has previously been shown that feedback devices have a positive effect on the quality of CPR (Havel 2010; Hostler 2011; Kim 2019; Kirkbright 2014; Wattenbarger 2019). Even a smartwatch with real-time feedback properties has been shown to improve the quality of CPR by increasing the depth of the compressions and lowering the compression rate (Lu 2019). However, the compliant surface underneath the patient falsifies the positive results if left unnoticed (Lin 2017; Niskisaki 2009; Noordengraaf 2009). In the present study, two separate defibrillators were used to calculate the real depth to which the chest was compressed during CCs. Real-time results could not be seen, and the data were calculated afterwards. Unfortunately, there are now only a few devices on the market that can show the real CC depth during the resuscitation attempt. Based on the present study, real-time feedback devices should be used in all resuscitation attempts to ensure high-quality CPR, and, if resuscitating on a compliant surface, sufficient compression depth should be ensured.

There are limited patient groups that might benefit from on-going resuscitation during transport (Truhlář 2015) and also limited evidence recommending routine transportation with ongoing CPR (Stub 2015). Decisions about transportation with ongoing CPR should be based on patient selection, treatment options available locally (e.g. PPCI, pulmonary embolectomy) and the availability of methods for maintaining circulation during and after the ambulance/helicopter transport (Forti 2014; Wagner 2010).

The transportation of the CA patient should be very carefully considered. Although the feedback devices improve the CPR quality, it is crucial to limit these special circumstances to the patients who may benefit from it. The risk for the rescuer must also be considered if a mechanical device is not used. Performing CCs in a moving ambulance puts the paramedic in immediate risk for injury.

6.3 Injuries

Fifty-four (32 %) patients suffered CPR-related injuries out of all the patients included in this study. The majority of the injuries were fractures of the ribs and sternum. Life-threatening injuries were seen only in a few patients. Ruptures of the

myocardium seen in patients were in infarcted areas of the myocardium and were most likely unavoidable if CCs need to be performed. Only one patient had a laceration in the spleen, causing haemorrhage up to one litre. Although life-threatening injuries were seen, none had an impact on the cause of death.

After the implementation of new resuscitation guidelines in 2010, incidence of injuries increased from 32 to 40 %. Forensic autopsy, being the most detailed and descriptive method for detecting injuries, revealed an increase from 42 to 64 % after the implementation of the new guidelines. Depth categories <50 mm, 50–60 mm and >60 mm yielded injury percentages of 28 %, 27 % and 49 %, respectively. Jin et al. (2017) detected a similar increase in the incidence of injuries in a study where potential CC-related injuries before and after the implementation of the 2010 guidelines were detected using only multi-detector CT. Potentially life-threatening injuries were only seen in the post-implementation group. Men were more likely to sustain injuries, which contradicts the findings in earlier studies (Black 2004, Pinto 2013).

Depending on the modality used to detect CPR-related injuries, the incidence of injuries varies widely (Hoke 2004, Miller 2014). In a forensic autopsy-based study (Black 2004), rib fractures were seen in 29 % and sternal fractures in 14 % of CA victims, whereas a Japanese forensic pathologist observed rib fractures in 52 % and sternal fractures in 39 % of their autopsy cases (Hashimoto 2007). Both studies were done before the implementation of the 2010 guidelines. A noticeable discrepancy in the percentage of myocardial ruptures is seen in the studies by Beom (2017), Kashiwagi (2015) and Smekal (2013). Incidence varies from 0.9 % to 29 %. In our study, 6.3 % of the patients had a rupture in the myocardium, which is an alarmingly high incidence.

After the implementation of 2010 guidelines, there was a distinct rise in the percentages of injuries. However, similar percentages have been published years before the guidelines with deeper chest compression recommendations. This study was the first study to analyse the incidence of injuries with data of actual chest compression used. In earlier studies assumptions of chest compression depths could have been made only based on recommendations on chest compression depth used.

Injuries to the chest wall, intra-thoracic organs, as well as CPR itself, can have negative effect on haemodynamics and on respiratory system compliance. Because of the injuries, changes in the chest wall, e.g. multiple rib fractures, can decrease thoracic stiffness and functional residual capacity (Azeli 2019). Lacerations to the great vessel or heart can cause major bleeding. Left ventricular outflow tract obstruction, seen during CPR, is associated with a poor outcome (Catena 2019).

Deeper CCs are associated with higher rates of ROSC and with better defibrillation success rate in patients presenting VF or pVT as an initial rhythm (Edelson 2006; 2008; Li 2008; Ristagno 2007). Considering this, should we increase the recommended depth of CCs even further? On the basis of the current study, the maximum depth should be 6 cm. The present data do not support a depth of compression exceeding 6 cm. Deeper compressions might increase the risk of injuries beyond an acceptable level. After the article, ‘Deeper chest compression – more complications for cardiac arrest patients?’ was published, the ILCOR and ERC recommended that CC should not exceed 6 cm. If there is any suspicion of potentially life-threatening CPR-related injuries, patients should be examined using multi-detector CT.

6.4 Quality of Life after Cardiac Arrest

QoL six months after CA was found to be good in the present study, and the findings are in line with other studies (Beesems 2014; Elliot 2011; Meaney 2013; Wilson 2014). The QoL after CA was comparable to that before CA and was the only significant factor in predicting better QoL after CA even when TH, PPCI, CABG, initial rhythm, age, gender, comorbidities and the time interval of ROSC were taken into consideration. Patients with better QoL before CA and fewer comorbidities were the same patients that were selected for invasive procedures. In previous studies, there are conflicting results with TH and the association with neurological outcomes (Bernard 2002; Bro-Jeppesen 2009; Callaway 2014; Hypothermia After Cardiac Arrest Study Group 2002; Oddo 2006; Sunde 2007). After the study on targeted temperature management (TTM) (Nielsen 2013) was published, the use of therapeutic hypothermia was widely changed to TTM.

Ischemic heart diseases are the leading cause of death and represent the majority of underlying causes in OHCA and IHCA patients. Coronary angiography and percutaneous coronary intervention play a key role in post-resuscitation management. In 80 % patients with STEMI, occluded culprit vessel can be identified in angiography, whereas in non-STEMI patient the corresponding number is approximately 30 % (Kern 2015). Patients with STEMI before CA benefit from early coronary intervention (Callaway 2014; Scholz 2018). In patients with STEMI, even shorter patient-specific door-to-balloon time has been consistently associated with lower mortality over time (Nallamothu 2015; Scholz 2018). No evidence of

immediate coronary angiography for non-STEMI patient after ROSC exists, but individual consideration is advised.

CPR is teamwork at its best. All the key elements should be timed accordingly, and resuscitation and post-resuscitation care in the ICU are highly organised and monitored. Still, to date, there are no guidelines on CA victims' rehabilitation. There are no randomised studies comparing different rehabilitation options. In many cases, at least in Finland, it is almost impossible to study retrospectively a patient's post-resuscitation care and rehabilitation when they are discharged from the hospital.

6.5 Limitations of the study

Studies I, IV and V were single-centre studies. It is, therefore, possible that the results may not apply to distinct patient populations or in different healthcare settings.

In study I, some of the factors affecting short-term survival were not included in the multivariate analysis due to lack of data (e.g. adequate compression depth during CPR). In 11 % of the cases, ROSC was not achieved and the determination of the aetiology was based on a consultant's opinion of pre- and peri-arrest factors and the patient's history. The time frame of 20–720 min for preceding subjective antecedents and vital dysfunctions simplifies deteriorations of different durations but, at the same time, allows these factors to be utilised in a multivariate logistic regression model.

In study II, the most important limitation is that the study was conducted using a manikin in a simulated setting. Manikins are designed to simulate basic human chest characteristics, but the individual variability in compliance and elasticity is lacking. It is important to point out that simulated settings with an ambulance speed of 40–60 km/h cannot recreate the same environment and amount of stress for the rescuer as an actual resuscitation attempt. In a real-life situation, the positive stress of the rescuer could improve the performance, but the unstable environment and high speed of the moving ambulance could hamper the quality of CPR and put the rescuer at risk of serious injuries.

The observational nature of study III and its small number of patients may limit the interpretation of the results, but the double accelerometer study protocol were implemented on real CA victims, which offered more reliable data than manikin studies.

In study IV, the limitations are mostly related to CC data; the QCPR data were only recorded from the arrival of the MET, and, though a backboard was used, the mattress effect is uncounted in the compression depth. Also, missing data (QCPR

and possible medical information) may bias the interpretation of the data. A strength of the study is that injuries were analysed with the actual compression depth, not on an assumption of CC depth, based on resuscitation guidelines.

The retrospective nature, the low number of patients per year and the missing data for 24 patients can be considered as limitations to study V. In this study post-resuscitation EQ-5D data were analysed with pre-resuscitation EQ-5D data, giving more exact information about the actual change or impact of the CA on the patient's life.

6.6 The Future Research

In the field of resuscitation science, new information on technical innovations, immediate post-resuscitation care and medical interventions are emerging. Studies on how these new innovations effect primary or secondary survival are being published. Yet, to date, there is no protocol for how the rehabilitation of post-CA patients should be organised and no information about which patients would benefit from structural rehabilitation. Are some of the costly post-resuscitation benefits lost in the following months when patients are discharged from the hospital? Currently, there are no recommendations on how to evaluate or report CA patients' rehabilitation and its quality parameters. Also, when studying the patient's quality of life after CA, it is highly important that all the factors favouring, or not favouring, invasive treatment protocols are reported so that bias in the interpretation of the results and positive outcomes can be avoided.

High-quality CC are the cornerstone of CPR. The first mechanical CC devices were developed at the beginning of the 1960s, but, in the 2000s, these devices were taken into clinical use. CCs, manually or mechanically performed, can cause serious complications to the patient. We know that with the implementation of the 2010 resuscitation guidelines, the incidence of injuries rose. Because high-quality CCs are a crucial part of resuscitation, we have to accept the risk for iatrogenic injuries. In future studies the quality of CPR, especially real chest compression depth, potential oblique vs. perpendicular chest compressions, should always be analysed together with injury findings.

7 SUMMARY AND CONCLUSIONS

The purpose of this thesis was to study the underlying reasons for in-hospital cardiac arrest and analyse if the aetiology, subjective antecedents or possible preceding vital dysfunctions are associated with long-term survival. A second purpose was to study the quality of chest compression during ambulance transportation and in-hospital cardiac arrest resuscitation attempts. The main focus during the transportations was to analyse if the quality can be improved with audiovisual feedback. The potential effect of mattress/stretchers on CPR during IHCA was also analysed. The most important and cornerstone of this thesis was to analyse the incidence of injuries associated to chest compressions. As a closing and the final link of this thesis was to investigate the quality of life six months after cardiac arrest and the factors effecting it.

Half of the cardiac arrests in general wards were due to cardiac reasons. Irrespective of the possible cardiac or non-cardiac aetiology for cardiac arrest, patients with both aetiologies have often preceding vital dysfunctions and subjective antecedents prior to cardiac arrest. IHCA patients with cardiac aetiology had more subjective antecedents, such as ‘chest pain’, prior to arrest (I). In light of this study it is crucial that the deterioration of the patients and their alarming symptoms are observed carefully on the wards so that their cardiac arrests can be avoided. If the aetiology of CA arrest is known, it is of utmost importance to consider possible aetiology-specific treatments in every resuscitation attempt.

In a simulated randomised setting, the real-time audiovisual feedback system improved the quality of chest compressions during ambulance transportation. When the mattress effect was taken into account using the dual-accelerometer device, the quality of chest compressions was suboptimal for most rescuers (II). Similar findings were observed in the observational IHCA resuscitation study. The real-time compression feedback device overestimated the chest compression depth performed on air mattresses leaving the real compression depth below the recommendations (III).

(IV) When the chest compression depths during cardiopulmonary resuscitation exceeded 6 cm in male patients the number of iatrogenic injuries increased. In female patients no such association was seen. The majority of the injuries were

spontaneously healing haematomas and rib fractures having only a minor impact on patients' recovery from resuscitation. It is important to realise that while there is an increased risk of complications with deeper compressions the injuries were by and large not fatal. On the basis of this study, the recommended maximum depth of compression should not exceed 6 cm.

(V) The quality of life six months after cardiac arrest was good in cardiac arrest survivors even though many had a high incidence of comorbidities. The best predictor for good quality of life after cardiac arrest was good quality of life prior to cardiac arrest. In every resuscitation attempt we have to contemplate which patient benefits from the resuscitation attempt and have best chances for surviving and when it is medically and ethically justified to allow natural death.

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Aetiology of in-hospital cardiac arrest on general wards

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Clinical paper

Aetiology of in-hospital cardiac arrest on general wards[☆]



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ABSTRACT

Aim: Aetiology of in-hospital cardiac arrests (IHCAs) on general wards has not been studied. We aimed to determine the underlying causes for IHCAs by the means of autopsy records and clinical judgement of the treating consultants. Furthermore, we investigated whether aetiology and preceding vital dysfunctions are associated with long-term survival.

Design and setting: Prospective observational study between 2009–2011 including 279 adult IHCA patients attended by medical emergency team in a Finnish university hospital's general wards.

Results: The median age of the patients was 72 (64, 80) years, 185 (66%) were male, 178 (64%) of events were monitored/witnessed, first rhythm was shockable in 42 (15%) cases and 53 (19%) patients survived six months. Aetiology was determined as cardiac in 141 events, 73 of which were due to acute myocardial infarction. There were 138 non-cardiac IHCAs; most common causes were pneumonia (39) and exsanguination (16). No statistical difference was observed in the incidence of objective vital dysfunctions preceding the event between the cardiac and non-cardiac groups (40% vs. 44%, $p = 0.448$). Subjective antecedents were more common in the cardiac cohort (47% vs. 32%, $p = 0.022$), chest pain being an example (11% vs. 0.7%, $p < 0.001$). Reviewing all 279 IHCAs, only shockable primary rhythm, monitored/witnessed event and low comorbidity score were independently associated with 180-day survival.

Conclusions: Cardiac aetiology underlies half of the IHCAs on general wards. Both objective and subjective antecedents are common. However, neither the cardiac aetiology nor the absence of preceding deterioration of vital signs were factors independently associated with a favourable outcome.

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Introduction

Survival to discharge after in-hospital cardiac arrest (IHCA) remains poor (10–20%) and it has practically remained unchanged through the recent decades.^{1–4} Cardiac arrest outside hospital is presumed to be of cardiac origin if no other definite signs exist; IHCAs on the other hand are often preceded by derangements in vital signs and cardiac aetiology is not assumed by default.^{5,6} Furthermore, IHCA victims often have several comorbidities in

addition to the concurrent illness, making the situation even more precarious.^{7,8}

Data on the definite aetiology of IHCAs on hospital general wards are very limited although the epidemiological understanding could result in improved and more prompt peri- and postarrest care. Bergum et al. studied 258 IHCAs and found cardiac causes to be responsible for 60% of the IHCAs.⁹ Wallmuller et al. reported similarly the percentage to be 63, and cardiac aetiology was associated with better outcome.¹⁰ However, in these thorough studies only 50% and 19% of IHCAs occurred on general wards while the rest occurred in specialized departments inside hospital like emergency departments, intensive care units and post anaesthetic care units.^{9,10}

The aim of this study was to shed light on the aetiology and antecedents to IHCAs occurring on hospital's general wards and investigate, whether the aetiology and antecedents are associated with outcome.

[☆] A Spanish translated version of the abstract of this article appears as Appendix in the final online version at <http://dx.doi.org/10.1016/j.resuscitation.2016.07.007>.

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Methods

Ethics

The Ethics Committee of the Tampere University Hospital (TAYS) approved the study protocol (Approval no: R08116; clinicaltrials.gov NCT00951704). National Institute for Health and Welfare and Regional State Administrative Agencies gave their consent to analyse forensic autopsy findings. Informed consent from the patient/relatives was waived as this study was purely observational.

Hospital

TAYS is one of the five university level tertiary referral centres in Finland with 71,000 somatic admissions per year. TAYS has a closed model, mixed surgical-medical intensive care unit (ICU) with 24 beds and approximately 2000 annual admissions. A separate cardiac ICU provides care for post operative cardiothoracic patients. Excluding the ICUs, paediatric wards, post anaesthetic care units and emergency department TAYS has 750 general ward beds, 6% of which have automated monitoring capabilities.

Definitions

IHCA was defined as cessation of cardiac activity, confirmed by the absence of signs of circulation, in a hospitalized patient who had a pulse at the time of admission.¹¹ Three outcomes were reported for IHCA patients in this study. ROSC (return of spontaneous circulation) was defined as return of a spontaneous perfusing rhythm with a palpable pulse.¹¹ Time-fixed outcomes, being alive 24 h and 180 days after the initial ROSC, were also reported. The main outcome was the 180-day survival. Vital dysfunctions preceding IHCA were defined as hospital's positive objective MET activation criteria present during a given time period before the events, and are also referred as afferent limb failures (ALFs) in the MET literature.^{12–15} Our hospital's objective MET criteria are presented in Table 3. Because the time period considered to be incorporated in ALF analysis is very disperse (starting from 15–60 min before the event and ending at 420–1440 min before the event),^{12–15} we defined the time frame in this study to be 20–720 min. Definitions for subjective symptoms preceding IHCA (antecedents) are also presented in Table 3. Included symptoms were based on out-of-hospital cardiac arrest studies.^{16,17}

Medical emergency team

The medical emergency team (MET) was implemented in January 2009. It is led by an ICU physician accompanied by two ICU nurses. The MET operates 24/7, responding to both IHCA and other medical emergencies. During the study period, MET activation rate was approximately 10 calls per 1000 hospital admissions including IHCA and 8.4 per 1000 admissions if just medical emergencies were included.

Data collection and exclusion criteria

Data on IHCA were routinely prospectively collected by the MET attending the resuscitation attempts during the study period of 2009–2011. Known data on comorbidities, preceding vital dysfunctions, subjective antecedents and survival were noted from patient records. Age-adjusted Charlson comorbidity index (CCI) was calculated for each patient; the total score presents the cumulative negative impact that patient's diseases and age have on favourable outcome.¹⁸

Table 1

Specific reason for in-hospital cardiac arrest.

Cardiac reason for IHCA n = 141	
Acute myocardial infarction	73
Myocardial ischaemia (no acute infarction)	26 ^a
Cardiac tamponade	5
Congestive heart failure	16
Complication after invasive cardiac intervention	9
Other	
Dilated cardiomyopathy	2
Cardiac amyloidosis	2
Cor pulmonale (after chronic pulmonary embolism)	1
Atrial fibrillation	1
Perimyocarditis	1
Aortic stenosis	2
Aortic regurgitation	1
Mitral regurgitation	1
Ascending aortic dissection	1
Non-cardiac reason for IHCA n = 138	
Pulmonary embolism	12
Infection	
Pneumonia	39
Peritonitis	11
Urogenital infection	2
Erysipelas	1
Pancreatitis	3
Colechystitis	2
Sepsis NAS	6
Cirrhosis	3
Renal insufficiency	2
Exsanguination	
GI tract	10
Traumatic	3
Airway	1
Iatrogenic	2
Cerebral ischaemia	4
Anaphylaxis	2
Hyperkalemia	2
Hyponatremia	2
Hematologic malignancy	2
Malignant solid tumour	7
Mechanical airway obstruction	7
Vasovagal collapse	1
Acute mesenteric ischemia	1
Overdose of opioids/benzodiazepines	2
Hypoxia due to chronic lung disease	4
Reason unclear	7

Data are presented in numbers. IHCA, in-hospital cardiac arrest; NAS, not further specified; GI, gastrointestinal.

^a In one case ischaemia was provoked by low hematocrit.

In case the resuscitation was successful or autopsy was not deemed necessary, aetiology of the cardiac arrest was classified according to the expert opinion of the consultant(s) responsible for the patient. The 'consultant's expert opinion' refers to the final conclusion of the aetiology (obtained from the patient records and/or the death certificate) after consultant(s) had assessed all relevant patient history and conducted all diagnostic tests and interventions deemed necessary; it does not refer to the first impression of the aetiology possibly recorded to the Utstein-style resuscitation form. Study personnel did not make assumptions about the aetiology.

No autopsies were conducted as part of this study protocol. Forensic autopsies must be conducted in certain situations according to the law and the cause of death investigation is led by the police. Medical autopsies are conducted if deemed necessary by the consultant responsible for the patient (e.g. the cause of death is considered uncertain). If either forensic or medical autopsy was conducted, the cause of the cardiac arrest was obtained from the autopsy records in case no ROSC was achieved or if ROSC was achieved but patient died during the following hours/day(s).

Paediatric IHCA were not included in this study. IHCA outside the general wards were excluded from further analyses.

Table 2
Patient characteristics, primary rhythm and outcome.

	IHCA due to cardiac aetiology (N = 141)	IHCA due to non-cardiac aetiology (N = 138)	p-value
Patient characteristics			
Age (median; Q ₁ , Q ₃)	74 (64, 82)	70 (63, 77)	0.010
Sex (male)	94 (67)	91 (66)	0.898
Age-adjusted CCI (mean ± SD)	5.3 ± 2.4	4.8 ± 2.7	0.112
Arterial hypertension	88 (62)	78 (57)	0.316
Coronary artery disease	72 (51)	34 (25)	<0.001
Atrial fibrillation	44 (31)	35 (25)	0.279
Cardiomyopathy	4 (1.4)	0 (0.0)	0.122
Chronic heart failure	43 (31)	23 (17)	0.007
Aortic stenosis	13 (9.2)	4 (2.9)	0.043
Peripheral artery disease	22 (16)	15 (11)	0.244
Diabetes	44 (31)	36 (21)	0.345
Asthma	8 (5.7)	12 (8.7)	0.328
Chronic obstructive pulmonary disease	13 (9.2)	8 (5.8)	0.279
Renal insufficiency	23 (16)	13 (9.4)	0.086
Dementia	5 (3.5)	3 (2.2)	0.723
Malignancy	13 (9.2)	30 (22)	0.004
Previously healthy	4 (2.8)	4 (2.9)	1.000
Primary rhythm			
Asystole	45 (32)	47 (34)	
Pulseless electrical activity	51 (36)	78 (57)	
Ventricular tachycardia	9 (6.4)	2 (1.4)	<0.001
Ventricular fibrillation	30 (21)	1 (0.7)	
Unclear	6 (4.3)	10 (7.2)	
Monitored/witnessed arrest	91 (65)	87 (63)	0.795
Aetiology determination and outcome			
Autopsy conducted	81 (57)	72 (52)	0.376
Clinical judgement	60 (43)	66 (48)	
ROSC	72 (51)	68 (49)	0.765
Alive at 24 h	54 (38)	60 (43)	0.379
Alive at 180 days	29 (21)	24 (17)	0.499

Data are presented as numbers (percentages) if not otherwise indicated. IHCA, in-hospital cardiac arrest; CCI, Charlson comorbidity index; Malignancy, malignant solid tumor or hematologic malignancy; ROSC, return of spontaneous circulation.

Table 3
Comparison of antecedents to IHCA related to cardiac vs. non-cardiac aetiology.

	IHCA due to cardiac aetiology (N = 141)	IHCA due to non-cardiac aetiology (N = 138)	p-value
Documented objective MET activation criteria (20–720 min before the IHCA)			
Respiratory rate (<5 or >24/min)	13 (9.2)	17 (12)	0.403
Peripheral arteriolar O ₂ saturation (<90%)	29 (21)	30 (22)	0.811
Heart rate (<40 or >140/min)	12 (8.5)	18 (13)	0.222
Systolic blood pressure (<90 mmHg)	16 (11)	8 (5.8)	0.222
Any objective criteria	56 (40)	61 (44)	0.448
Multiple objective criteria	13 (9.2)	11 (8.0)	0.710
Recorded subjective antecedents (20–720 min before the IHCA)			
Respiratory distress	42 (30)	31 (23)	0.164
Chest pain	15 (11)	1 (0.7)	<0.001
Arrhythmias	2 (1.4)	1 (0.7)	0.574
Upper abdominal pain	3 (2.1)	4 (2.9)	0.681
Back pain	2 (1.4)	2 (1.4)	0.983
'Cold sweat'	5 (3.5)	5 (3.6)	0.972
Decrease in the level of consciousness	8 (5.7)	16 (12)	0.078
Any subjective antecedent	66 (47)	44 (32)	0.022
Multiple subjective antecedents	11 (7.8)	12 (8.7)	0.786

Data are presented as numbers (percentages). IHCA, in-hospital cardiac arrest; MET, medical emergency team.

Statistical analysis

Data are presented as numbers (percentages) if not otherwise indicated. The chi-square test, Student's *t*-test, Fisher's exact test and Mann–Whitney *U* test were used for comparisons between groups as appropriate. Multivariate logistic regression was applied with 'enter' model and the Hosmer–Lemeshow test was conducted to report the goodness-of-fit of the model. Tests were two-sided; $p < 0.05$ was considered significant and 95% confidence intervals were reported where appropriate. SPSS version 20 for Windows (SPSS Inc., Chicago, IL, USA) was used.

Results

Study population

Fig. 1 presents the excluded cases and the final cohort of 279 general ward patients attended by the MET because of an IHCA. Median age was 72 (64, 80) years, 185 (66%) were male and mean age-adjusted CCI was 5.0 ± 2.6 . Primary rhythm was shockable (VT/VF) in 42 (15%) of the patients, ROSC was achieved in 140 (50%) cases and 114 (41%) patients survived the first 24 h. After six months, 53 (19%) patients were alive.

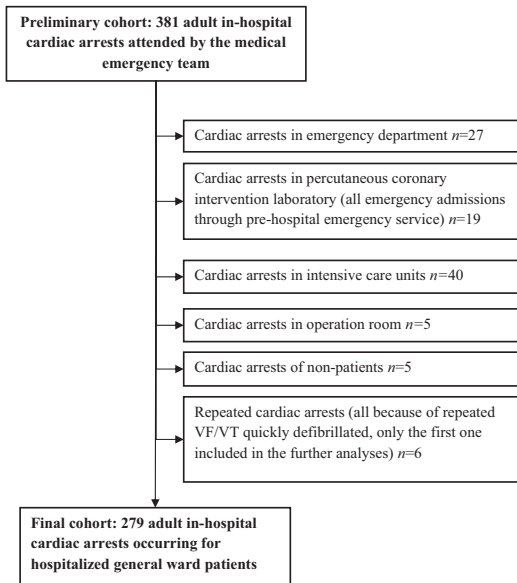


Fig. 1. Final cohort with the excluded cardiac arrests inside hospital during the study period. VF, ventricular fibrillation; VT, ventricular tachycardia.

Aetiology

An autopsy was conducted in 153 (55%) patients, 84 of which were forensic autopsies and 69 medical autopsies. For the remaining 126 (45%) patients, the reason for IHCA was clinically assessed by the treating consultant(s); in 30 of these cases ROSC was not achieved and thus no further clinical or laboratory tests were conducted. Fig. 2 presents the determination of IHCA aetiology either as 'cardiac' or 'non-cardiac' and Table 1 lists the specific underlying aetiologies in both sub cohorts. Among patients with cardiac aetiology ($n = 141$, 51%), acute myocardial infarction was the most common cause for IHCA. Infections were the most prevalent sub group in 'non-cardiac' category. The method for aetiology determination (autopsy vs. clinical judgement) was not associated with the determined aetiology (aetiology was determined as 'cardiac' among 53% of the autopsied patients vs. 48% among the non-autopsied patients ($p = 0.376$)).

Cardiac vs. non-cardiac aetiology of IHCAs—characteristics and antecedents

Patients in the 'cardiac' and 'non-cardiac' cohorts had similar distribution of gender and cumulative comorbidity, but the 'cardiac' cohort was older (Table 2). Regarding the individual comorbidities, coronary artery disease, chronic heart failure and aortic stenosis were more prevalent in the 'cardiac' cohort. Solid or hematologic malignancies were more common among the 'non-cardiac' IHCA patients. Shockable rhythms were more common in the cardiac cohort, but non-shockable rhythms prevailed in both subcohorts. There were no differences in survival between the cohorts.

Altogether 117 (42%) IHCA patients had had positive objective MET activation criteria 20–720 min before the event, but there were differences between the 'cardiac' or 'non-cardiac' groups (Table 3). However, the overall incidence of subjective antecedents was higher in the 'cardiac' cohort, and from the individual antecedents 15 patients in the 'cardiac' cohort had had chest pain while only one had complained this symptom in the 'non-cardiac' cohort.

Table 4

Multivariate logistic regression analysis of factors independently associated with 180-day survival.

	Multivariate analysis		
	Odds ratio	95% CI	p-value
Shockable rhythm (VT/VF)	8.87	3.54–22.2	<0.001
Monitored/witnessed IHCA	2.46	1.13–5.36	0.024
Age-adjusted CCI	0.86	0.75–0.99	0.041
Any subjective antecedent	0.54	0.25–1.16	0.113
Cardiac aetiology	0.59	0.26–1.33	0.202
Any objective MET criteria	0.70	0.34–1.43	0.324
Sex (male)	0.81	0.40–1.65	0.563

CI, confidence interval; VT, ventricular fibrillation; VF, ventricular tachycardia; IHCA, in-hospital cardiac arrest; CCI, Charlson comorbidity index; MET, medical emergency team.

Shockable primary rhythm, monitored/witnessed IHCA and lower age-adjusted CCI were independently associated with 180-day survival, while cardiac aetiology and antecedent-free event were not (Table 4). The Hosmer–Lemeshow Chi-square test for multivariate logistic regression model was 4.44 ($p = 0.816$) indicating a good fit of the model.

Discussion

This study has two main findings. First, half of the IHCAs on hospital general wards were of cardiac origin and these IHCAs were more commonly preceded by subjective antecedents, especially chest pain, as compared to IHCAs of non-cardiac origin. Second, the multivariate logistic regression model demonstrated, that it is not the aetiology but low comorbidity, witnessed/monitored arrest and shockable primary rhythm that are independently associated with better long-term survival. To the best of our knowledge this is the first study to investigate the adjusted association between the aetiology of IHCA and outcome.

We investigated the aetiology of IHCAs on general wards, where continuous monitoring and staff resources are limited as compared to, for example, ICUs and emergency departments. Cardiac causes were still more common than non-cardiac causes, however approximately 10% less prevalent than reported in studies including all hospital departments.^{9,10} Of the specific causes of IHCAs, acute myocardial infarction and myocardial ischaemia without later findings of infarction together accounted for 35% of the arrests. This finding is of utmost importance, considering that only 15% of all general ward IHCAs had a shockable primary rhythm. Congestive heart failure progressing to IHCA was the second largest individual reason for arrest within the cardiac aetiology group. Following pneumonia, exsanguination and pulmonary embolism were the second and third most common individual aetiologies for IHCAs in the 'non-cardiac group'. Aetiology of altogether 112 IHCAs could be directly classified according to the '4H4T'-rule,⁶ even though excluding infections which potentially caused IHCAs due to hypovolaemia/hypoxia as well. This observation underlines the importance of including '4H4T'-rule in the advanced life support algorithm.⁶

Two thirds of the general ward IHCAs in our study were witnessed/observed. This occurrence has previously been associated with better outcome and was also confirmed in the present study.^{19,20} In many IHCA studies the proportion of witnessed/observed cardiac arrests has been as high as 85–92% and it has been discussed, that previous IHCA studies represent poorly the actual patient population on general wards because of the high proportion of ICU/emergency department/cardiac care unit patients.^{9,20,21} Brindley et al. excluded patients allocated to 'critical care units' and found that 58% of the IHCAs were witnessed/observed, which is in line with our findings.¹⁹ Still, two

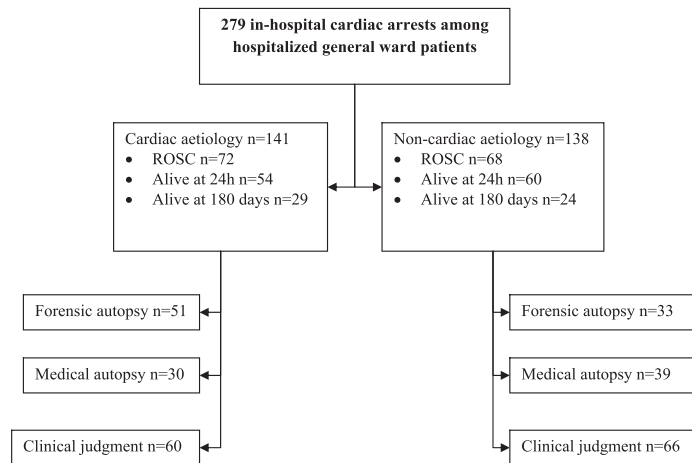


Fig. 2. Survival and methodology for determination of the aetiology among the study population. ROSC, return of spontaneous circulation.

thirds of patients experiencing a witnessed/observed cardiac arrest on general wards is rather high. However, today many hospitals have rapid response systems,²² and although we did not record the exact number, there were several cases of IHCA where the arrest occurred during MET review and thus the arrest was naturally 'monitored and observed'.

Both vital dysfunctions and subjective antecedents were common before IHCA, despite our hospital had implemented MET at the time this study was initiated. Similar findings have been observed in Australia: implementing a rapid response system did not automatically eliminate the intervention delays in patient care.²³ It is pivotal to disengage these afferent limb failures.^{12–15} Regardless of the fact that in our study these antecedents were not independently associated with worse outcome, some IHCA could have been avoided either by appropriate interventions or ethically sound treatment limitations.

Low comorbidity, witnessed/monitored arrest and shockable primary rhythm were independently associated with six months' survival in a multivariate regression model. These pre- and peri-arrest factors have previously been reported to be associated with hospital- or short-term survival in univariate or multivariate analyses.^{7,10,20,21,24} Our study also confirmed that these variables are associated with long-term survival, even when adjusted for gender and, for the first time, for preceding derangements and aetiology. One could have suspected that cardiac aetiology would have been associated with improved outcome, but this was not the case even with the other outcomes (ROSC, 24 h survival). Wallmuller et al. found cardiac aetiology to be associated with survival in a univariate analysis.¹⁰ Naturally 'cardiac aetiology' depends on how the causes are classified, but in this study the classification was quite comparable to our study.¹⁰ On the other hand, we studied the IHCA on general wards, while Wallmuller et al. studied IHCA mainly at the ICU of the emergency department. Our results show that if an IHCA occurs on general wards, immediate CPR (cardiopulmonary resuscitation) and shockable rhythm are the key factors for survival while comorbidities reduce probability of desired outcome.

This study has several limitations. First, as a single centre study our results may not apply in different health care settings or with distinct patient populations. Second, we could not include some factors known to be associated with at least short term survival in our multivariate analysis (e.g. adequate compression depth during CPR²⁵). Third, in 11% of the cases no ROSC was achieved but autopsy

was not deemed necessary; thus the consultant(s) aetiology determination relied only on patient history and pre- and peri-arrest factors. Fourth, the time frame of 20–720 min for preceding vital dysfunctions and subjective antecedents simplifies deteriorations of different durations, although it enables feasible utilization of these factors in multivariate logistic regression model and this same methodology is used in MET studies.^{12–15} These limitations should be weighed against the strengths of this study. Aetiology was determined by autopsy for 55% of the patients. This percentage is exceptionally high as compared to other aetiological studies and autopsy after an unsuccessful resuscitation attempt has been suggested as 'golden standard' for studies on the cause of cardiac arrest.^{26,27} We used age-adjusted charlson comorbidity index as a continuous variable to take into consideration the possible negative effect of cumulative age-related comorbidity in our analyses.²⁴ Third, despite a single centre design, TAYS is one of the five tertiary referral centres in Finland providing the most advanced care and the general wards represent all major specialties and our study population was very heterogeneous.

Conclusions

In-hospital cardiac arrests on general wards are caused by cardiac reasons in half of the cases. Both cardiac and non-cardiac IHCA are often preceded by vital dysfunctions and subjective antecedents. Subjective antecedents, such as 'chest pain', are more common among IHCA of cardiac aetiology. In case of an IHCA on a general ward of the hospital, low comorbidity, witnessed/monitored arrest and shockable primary rhythm are factors independently associated with better long-term survival.

Conflict of interest statement

Authors declare no conflicts of interests.

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PUBLICATION
II

The quality of manual chest compressions during transport - effect of the mattress assessed by dual accelerometers

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The quality of manual chest compressions during transport – effect of the mattress assessed by dual accelerometers

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Background: The quality of cardiopulmonary resuscitation (CPR) has an impact on survival. The quality may be impaired if the patient needs to be transported to the hospital with ongoing CPR. The aim of this study was to analyse whether the quality of CPR can be improved during transportation by using real-time audiovisual feedback. In addition, we sought to evaluate the real compression depths taking into account the mattress and stretcher effect.

Methods: Paramedics ($n = 24$) performed standard CPR on a Resusci Anne Mannequin in a moving ambulance. Participants were instructed to perform CPR according to European Resuscitation Council Resuscitation guidelines 2010. Each pair acted as their own controls performing CPR first without and then with the feedback device. Compression depth, rate and no-flow fraction and also the mattress effect were recorded by using dual accelerometers by two Philips, HeartStart MRx Q-CPR defibrillators.

Results: In the feedback phase, the mean compression depth increased from 51 (10) to 56 (5) mm ($P < 0.001$), and the percentage of compression fractions with adequate depth was 60% vs. 89% ($P < 0.001$). However, taking account of the mattress effect, the real depth was only 41 (8) vs. 44 (5) mm without and with feedback, respectively ($P < 0.001$). The values for compression rate did not differ.

Conclusions: CPR quality was good during transportation in general. However, the results suggest that the feedback system improves CPR quality. Dual accelerometer measurements show, on the other hand, that the mattress effect may be a clinically relevant impediment to high quality CPR.

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DESPITE the rapid development of medical devices and technical innovations in general, high-quality manual chest compressions are still the cornerstone of effective cardiopulmonary resuscitation (CPR). Current European Resuscitation Council (ERC) guidelines from 2010 emphasise the importance of minimising interruptions in chest compressions and an adequate compression depth of at least 5 cm.¹ Indeed, studies have shown that the outcome of cardiac arrest patients is related to the quality of CPR.^{2,3} Concomitantly, research has shown that quality has often been suboptimal during resuscitation.^{4,5} Although CPR in a moving emergency vehicle is not customary at least in a European setting, continuous CPR during transportation to

hospital is recommended for limited patient groups, such as hypothermic patients.⁶ In addition, there are emergency medical systems where rescuers are instructed to transport all cardiac arrest patients to hospital with ongoing CPR.⁷ Failure to maintain high-quality CPR during ambulance or helicopter transportation^{8–10} may partly explain the persistently poor survival of these patients.

Several studies have shown that the use of real-time audiovisual feedback can improve the quality of CPR in both out-of-hospital and in-hospital cardiac arrest.^{11–13} The first generation of real-time audiovisual feedback devices use accelerometer and force signals to calculate the movement of the CPR sensor enabling the estimation of the depth of chest

compression. Unfortunately, majority of these devices cannot measure bias in compression depth possibly due to mattresses on beds and stretchers, and therefore possibly resulting in too shallow compressions.¹⁴⁻¹⁶ This study aimed to investigate whether the quality of CPR, as quantified by compression depth, compression rate and no-flow fraction, can be improved during ambulance transportation by using real-time automated feedback. The primary end point was the compression depth. Our secondary aim was to evaluate whether the real compression depth which takes the mattress/stretcher effect into consideration deviates from the compression depth values given by the feedback device. We hypothesised that the automated feedback device improves the quality of CPR, but the mattress/stretcher effect may hamper the quality.

Methods

Study design

The study was performed with the approval of the Pirkanmaa Hospital District Science Center and the Ethics Committee of Tampere University Hospital (Approval no: R08116). The study was a non-randomised, prospective mannequin study, where each participant performed CPR first without and then with the feedback device. The study design was executed knowingly as non-randomised and in a predefined order to avoid any learning effect in the control phase.

Participants and equipment

Altogether, 24 paramedics from the Tampere Regional Rescue Department participated in this study. Each participant signed an informed consent form before participation so that the collected data could be used in the study. CPR was performed on a Resusci Anne® Mannequin (Laerdal Medical AS, Stavanger, Norway). The trachea of the mannequin was intubated before the study protocol and then manually ventilated by the rescuers during CPR. Quality of ventilation was not recorded.

The parameters related to the quality of the chest compression and the mattress effect were recorded using two accelerometers and two HeartStart MRx defibrillators designed by Philips Health Care (Andover, MA, USA) and Laerdal Medical AS. The accelerometer is capable of measuring and recording CPR quality parameters such as chest compression rate and depth, compression with incomplete chest release and compression duty cycle by compression-to-compression. It also records the

number of shocks delivered per patient and the hands-off time before and after each shock, calculates actual chest compressions performed per minute and time without chest compressions (no-flow time).^{17,18}

We used a modified Mercedes Benz Sprinter ambulance for the transportation and the simulated resuscitations were performed on Pensi 2000 MA Multifunction Stretcher, mattress thickness 7 cm (Pensi Rescue Oy, Sastamala, Finland).

Study protocol

The participants in pairs were instructed to perform standard CPR as they would perform it in an actual resuscitation attempt. Each simulated resuscitation attempt was performed according to ERC 2010 Resuscitation guidelines, except for defibrillation and drug administration, which were omitted from this study.¹ Each pair acted as their own controls performing first standard CPR without feedback and thereafter with feedback as the intervention. In the non-feedback phase, the defibrillator screen and the accelerometer display were covered and the guidance voice was silenced. Before the feedback phase started, we ensured the correct use of the accelerometer and the defibrillator by adequate demonstration of the devices. We installed a digital video camera inside the ambulance and recorded the performance of each pair for purposes of analysis.

The accelerometer, measuring chest compression quality, was placed on the mid-sternal area of the mannequin. The second accelerometer measuring the mattress effect was attached firmly to the mannequin's back in a straight line with the upper accelerometer. The upper accelerometer on the mid-sternal area measured the compression of the chest, mattress and stretcher together, while the lower one measured the deflection of the mattress and the stretcher only. Both accelerometers were connected to separate defibrillators.^{16,18,19} Target values for compression depth and compression rate were determined a priori based on current resuscitation guidelines: compression depth 50–60 mm and compression rate 100–120/min. No-flow fraction was merely calculated from the data.

The ambulance drove two 10-min laps per pair on a predetermined course on a public road. The speed varied from 40 km/h to 80 km/h. During the first lap, the each pair performed CPR without feedback (control) and during the second lap with feedback (intervention). The chest compressions were performed standing beside the mannequin.

Collection and analysis of data

Detailed information on the chest compressions and the mattress and stretcher deflection during the study protocol was stored on a memory card and then transferred to a personal computer. The data were further processed and analysed with Windows-based Q-CPR Review software (v2.1.0.0. Laerdal Medical AS).

Each resuscitation session was divided into 30-s fractions/epochs for the evaluation of mean chest compression depth (mm), compression rate, incomplete chest release and no-flow fraction. The mattress and stretcher deflection was also analysed in 30-s epochs using the data from the second accelerometer. The real compression depth was calculated individually from the data of the two accelerometers. The actual compression depth (mean value in 30-s time epoch) was calculated by subtracting the compression depth from the second accelerometer (lower) from the first accelerometer (upper).

Statistical analysis

Statistical analyses were performed using IBM SPSS for Windows, PASW 19.0 software (SPSS Inc., Chicago, IL, USA). Mixed model analysis of variance (ANOVA) was used for the analysis of compression depth, compression rate and real compression depth using the feedback device as fixed factor and paramedic as a random factor.

The sample size was based on the decision to execute the study during one weekend (Saturday and Sunday), and all the paramedics on duty during that weekend were recruited.

Comparisons of continuous data were done with independent samples *t*-test and Mann-Whitney *U*-test. Binomial variables were analysed with χ^2 test to compare the overall effect of the feedback device. All data are expressed as mean (standard deviation) or median (Q_1 - Q_3), as appropriate. Two-sided *P*-value < 0.05 was considered statistically significant.

Results

Primary outcome: quality of CPR as analysed by a single accelerometer

The baseline characteristics of the participating paramedics are summarised in Table 1. The total number of 30-s epochs included in the analyses was 507, of which 252 were done without feedback and 255 with real-time audiovisual feedback. Switching from the non-feedback phase to the feedback phase was associated with an increase in the mean compression depth from 51 (10) to 56 (5) mm without subtracting the mattress effect (Tables 2, $P < 0.001$).

When analysed per paramedic, mixed model ANOVA revealed a deeper ($P = 0.003$) compression depth during the feedback phase than during the control phase (Fig. 1). When switching from the control phase to the feedback phase, the percentage of 30-s epochs with mean compression depth ≥ 50 mm increased from 50% to 89% ($P < 0.001$). The corresponding percentage of 30-s epochs with a mean compression rate of 100–120/min increased from 40% to 61% ($P < 0.001$). The total number of compressions with compression depth ≥ 50 mm increased from 56% (6810/12 267) to 78% (9845/12 555) ($P = 0.02$). Out of the total number of compressions, the percentage of compressions with incomplete chest release decreased from 6% (706/12 267) without feedback to 1% (130/12 555) with feedback ($P < 0.001$). Median no-flow fraction

Table 1

Baseline characteristics of the paramedics who participated in the study.

	Study population
<i>n</i> (%)	24
Age (years)	31 (27, 39)
Work experience (years)	7 (3, 13)

The data are given as mean (SD), or medians (Q_1 - Q_3).

Table 2

Quality of CPR of a resuscitation mannequin in a moving emergency vehicle. Quality was assessed during the control phase without any feedback of the quality of CPR and during real-time audiovisual feedback.

Variables	Study population (<i>n</i> = 24)		
	Control	Real-time audiovisual feedback	<i>P</i> -value
Mean compression depth (mm)	51 (10)	56 (5)	< 0.001
Mattress deflection (mm)	11 (3)	12 (2)	< 0.001
Real compression depth (mm)	41 (8)	44 (5)	< 0.001
Compression rate (/min)	104 (20)	103 (5)	0.55
No-flow fraction	0.09 (0.04, 0.13)	0.10 (0.05, 0.15)	0.82

The data are given as mean (SD) or median (Q_1 - Q_3).

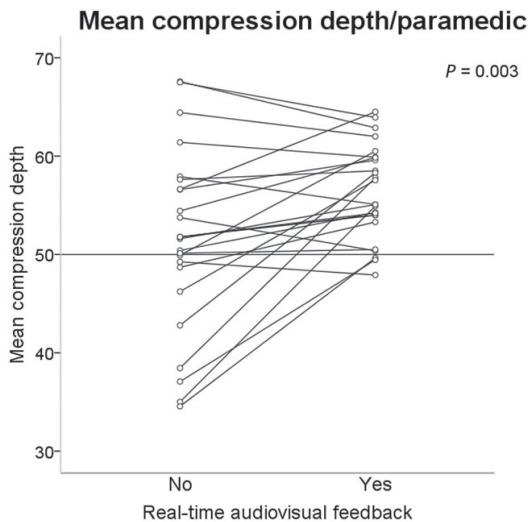


Fig. 1. Mean compression depth as achieved by 24 paramedics without (control) and with real-time automated feedback of the quality of cardiopulmonary resuscitation (CPR). Each line represents an individual paramedic.

without feedback was 0.09 (0.04, 0.13) and 0.10 (0.05, 0.15) with feedback ($P = 0.82$).

Secondary outcome: quality of CPR as analysed by two accelerometers

The mean values for the real compression depth are shown in Table 2. When the real-time audiovisual feedback was used during simulated CPR, the mattress and stretcher deflection increased from 11 (3) to 12 (2) mm ($P < 0.001$). When the mattress effect was taken into account with the dual accelerometer measurement, the mean compression depths were only 41 (8) and 44 (5) mm, in non-feedback and feedback phases respectively ($P < 0.001$). The percentage of 30-s epochs with compression depth ≥ 50 mm increased only 2.6%, but the proportion of compression depth being < 40 mm decreased with the feedback from 41% to 14% ($P < 0.001$). The total number of compressions with real compression depth ≥ 50 mm appeared to increase from 2365 (19%) to 3718 (30%) ($P = 0.22$) using real-time automated feedback but the difference was not statistically significant. The real compression depth per paramedic and the effect of the mattress and stretcher to the compression depth can be seen from Fig. 2.

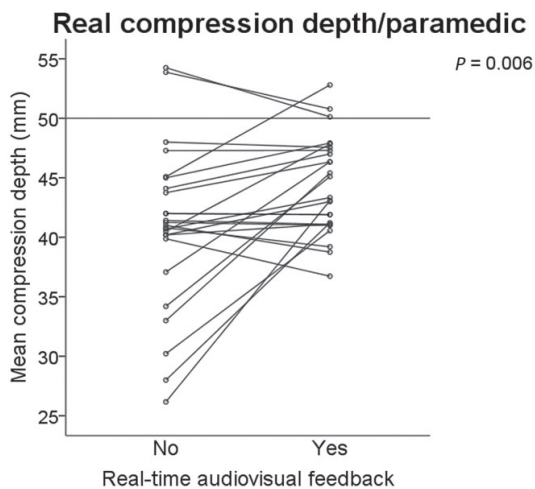


Fig. 2. Real depth, when the mattress and stretcher effect is taken into account. Each line represents an individual paramedic.

Discussion

This study shows that the quality of chest compressions, especially the compression depth and compression rate can be improved with the use of real-time audiovisual feedback device when CPR is performed in a moving emergency vehicle. When the mattress effect was not taken into consideration, the quality of chest compressions was fairly good even without the feedback system, but the use of the feedback device improved it significantly. During the audiovisual feedback phase, the chest compressions were deeper and the compressions were better in line with the current ERC guidelines.¹ The recommended compression depth was also achieved with smaller interindividual variation than without the use of the feedback. However, there were considerable interindividual differences even when CPR was performed using the feedback. Previously, it was shown that variation in compression quality increased during ground transportation in emergency vehicles and in the transition from ambulance to emergency department. All the resuscitations in that study were performed without the guidance of the feedback device.²⁰

The use of real compression depth by dual accelerometer instead of single accelerometer only demonstrated decisively that the mean compression depth was suboptimal. Depending on the surface, mean mattress compression may vary from a few millimetres to more than 10 mm.¹⁶ Compared with

hospital beds, ambulance stretchers are more flexible but the mattress is flatter. Nevertheless, the mattress and stretcher effect decreases the real compression depth significantly in an emergency vehicle setting. It is known that deeper compressions improve the success rate of defibrillation and produce higher rate of return of spontaneous circulation (ROSC). Therefore, unrecognised mattress effect may partly explain the poor outcome of out-of-hospital cardiac arrest patients.^{21–25} The mean compression rate was fairly constant throughout all the resuscitation attempts, but the use of feedback significantly reduced interindividual variation.

Although it would be desirable to achieve ROSC at the scene,²⁶ there are situations when resuscitation attempts may be prolonged (e.g. CPR of hypothermic patients, during thrombolysis for pulmonary embolism, poisoning), and therefore, occasionally, resuscitation during transportation is mandatory. Prolonged resuscitation, possible fatigue of the rescuer and unstable working conditions during transportation may impair the quality of the resuscitation. Earlier research has shown that the quality of CPR during transportation deteriorates in comparison to the quality of CPR at the scene.^{21,27} One solution to this problem would be mechanical chest compression devices that improve the quality of CPR and additionally reduce the risks for the rescuer.²⁸ Unfortunately, mechanical chest compression devices are not universally available. Thus another solution might be the use of automated audiovisual feedback to ensure the best possible quality of chest compressions. The future challenge for manufactures of feedback devices is to develop a device that is easy and quick to use and capable of measuring the real compression depth so that we can be sure that the compression depth is adequate.

This study has limitations. First, the study was a mannequin study. Although the mannequin simulates the characteristics of the human chest fairly well, it cannot simulate the individual variability of human chest compliance and elasticity, which may influence the quality of chest compressions and consequently the outcome of CPR. Second, the study was conducted in a simulated setting without the stress factor of a real resuscitation and without excess speed and with the possibility of positive Hawthorne effect.²⁹

A real-time audiovisual feedback system, a single-accelerometer or even better, a dual-accelerometer device improves the quality of chest compressions during transportation in an emergency vehicle. Further studies are needed to investigate the effect

of transportation on the quality of CPR in a clinical setting. More studies are also needed on performing manual chest compressions and estimating sufficient compression depth on a compliant mattress and stretcher.

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The other authors declare no conflicts of interest.

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PUBLICATION

III

Effect of mattress and bed frame deflection on real chest compression depth measured with two CPR sensors

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Short communication

Effect of mattress and bed frame deflection on real chest compression depth measured with two CPR sensors

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ABSTRACT

Aim: Implementation of chest compression (CC) feedback devices with a single force and deflection sensor (FDS) may improve the quality of CPR. However, CC depth may be overestimated if the patient is on a compliant surface. We have measured the true CC depth during in-hospital CPR using two FDSs on different bed and mattress types.

Methods: This prospective observational study was conducted at Tampere University Hospital between August 2011 and September 2012. During in-hospital CPR one FDS was placed between the rescuer's hand and the patient's chest, with the second attached to the backboard between the patient's back and the mattress. The real CC depth was calculated as the difference between the total depth from upper FDS to lower FDS.

Results: Ten cardiac arrests on three different bed and mattress types yielded 10,868 CCs for data analyses. The mean (SD) mattress/bed frame effect was 12.8 (4) mm on a standard hospital bed with a gel mattress, 12.4 (4) mm on an emergency room stretcher with a thin gel mattress and 14.1 (3) mm on an ICU bed with an emptied air mattress. The proportion of CCs with an adequate depth (≥ 50 mm) decreased on all mattress types after compensating for the mattress/bed frame effect from 94 to 64%, 98 to 76% and 91 to 17%, in standard hospital bed, emergency room stretcher and ICU bed, respectively ($p < 0.001$).

Conclusion: The use of FDS without real-time correction for deflection may result in CC depth not reaching the recommended depth of 50 mm.

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1. Introduction

There are several devices which monitor the quality of cardiopulmonary resuscitation (CPR) by analyzing chest compressions (CC) with a force and deflection sensor (FDS).¹ Unfortunately, a single FDS may overestimate compression depths on a compliant

surface (mattress effect) as the whole torso of the patient moves according to CCs.^{2–4} Human studies have shown that compression depth is often too shallow even when the mattress/bed frame deflection effect is not taken into account.^{5–7} Manikin studies have demonstrated that the mattress effect can be taken into account with two FDS devices.^{2,8} However, because the patient's individual characteristics vary, clinical studies are necessary for the validation of the manikin studies.

We sought to test the hypothesis that implementation of single-FDS system overestimates CC depths during clinical CPR. We specifically aimed to use two FDSs during real CPR attempts in order to analyze the mattress/bed frame effect and the risk of overestimating CC depth for a patient during in-hospital CPR attempts.

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Fig. 1. Backboard with a compression force and deflection sensor (FDS) set under the patient's back so that the dark line is at the patient's axillary level. The dimensions of the backboard were 62 cm × 78 cm × 0.8 cm and weight was 2.8 kg, placed under the patient across the bed and reached up from head-to-hips.

2. Methods

2.1. Study design

This prospective study was conducted at Tampere University Hospital (TAUH) between August 2011 and September 2012. All adult in-hospital cardiac arrest patients were considered eligible for inclusion. Because this was an observational study without a change of the clinical routine, the Ethics Committee of the TAUH waived the written informed consent (Approval no: R08116; clinicaltrials.gov NCT00951704).

2.2. Hospital

Details of the hospital and medical emergency team (MET) have been described in our previous reports.⁹ During the study period MET used two HeartStart MRx defibrillators with Q-CPR™ option (Philips Health Care, Andover, Massachusetts) and Laerdal Medical Ltd. (Stavanger, Norway) in each resuscitation attempt to record force and deflection signals with the two FDSs.¹⁰

Three bed types were used to evaluate mattress/bed frame effect during CCs (Table 1). A plywood backboard was used under the patients to minimize the mattress deflection as part of routine clinical care (Fig. 1).

2.3. Study protocol and compression depth measurement using two CPR sensors

The upper (anterior) FDS, which was also used to guide the CPR, was attached to patient's chest underneath rescuer's hands. The lower (posterior) FDS was pre-attached to the backboard. During resuscitation backboard was placed at a pre-specified location under the patient's back to ensure that the FDSs measured the

Table 1 Patients characteristics and data on chest compressions in each of the ten resuscitation attempts.

Patient	1	2	3	4	5	6	7	8	9	10
Age (years)	73	57	73	68	71	63	69	86	85	69
Gender	Male	Male	Male	Male	Male	Male	Male	Male	Male	Male
Height (cm)	177	174	173	158	180	175	178	172	187	180
Weight (kg)	98	89	71	76	70	120	90	80	90	93
Chest APD (cm)	25	27	20	21	23	28	22	21	24	25
25% of chest APD (cm)	6.25	6.75	5	5.25	5.75	7	5.5	5.25	6	6.25
Chest circumference (cm)	110	117	101	102	92	111	112	100	107	111
Bed type	ER	ER	ICU	GEL	GEL	ER	GEL	GEL	ICU	ICU
CC count (n)	463	6398	1511	459	246	51	387	372	48	323
CC force (kg)	42 (7)	49 (12)	40 (8)	51 (11)	41 (4)	51 (15)	37 (10)	43 (7)	48 (8)	40 (4)
CC leaning force (kg)	0.65 (0.0, 0.86)	1.15 (0.55, 1.83)	0.79 (0.40, 1.25)	0.03 (0.0, 0.25)	0.03 (0.0, 0.25)	1.44 (1.18, 1.84)	0.58 (0.36, 1.67)	0.35 (0.21, 0.48)	1.63 (0.20, 3.20)	0.73 (0.65, 0.86)
Matrix effect (mm)	11 (3)	12 (4)	14 (3)	15 (3)	11 (1)	16 (4)	16 (3)	8 (2)	15 (3)	15 (2)
Uncompensated measurement										
CC depth, mm	69 (4)	68 (9)	60 (6)	72 (9)	62 (4)	60 (13)	84 (9)	53 (3)	53 (3)	59 (4)
CC depth > 50 mm No. (%)	461 (99)	6323 (98)	1370 (91)	456 (99)	244 (99)	376 (84)	385 (99)	295 (79)	276 (85)	256 (99)
CC depth > 25% of the APD No. (%)	440 (95)	3359 (53)	1370 (91)	454 (99)	201 (82)	74 (16)	381 (98)	195 (52)	11 (3)	47 (18)
Compensated with mattress/bed frame effect										
CC depth, mm	58 (4)	56 (7)	46 (5)	57 (8)	51 (4)	44 (9)	58 (8)	44 (4)	38 (3)	44 (4)
CC depth > 50 mm No. (%)	452 (98)	5054 (79)	345 (23)	397 (86)	164 (67)	78 (17)	337 (87)	36 (10)	0 (0)	4 (1)
CC depth > 25% of the APD No. (%)	63 (14)	136 (2)	345 (23)	315 (68)	4 (2)	7 (2)	227 (59)	10 (3)	0 (0)	0 (0)

APD, anterior–posterior diameter; CC, chest compression; APD, anterior–posterior diameter; CC leaning force, residual leaning force between chest compressions. The data are presented as numbers, numbers and percentages, as median and 25–75% interquartile range (IQR) or as mean and standard deviation (SD) as appropriate (non-normal or normal distribution respectively).

movement along the same vertical line. The lower FDS was connected to the second defibrillator via cable (Fig. 1).

2.4. Collection and analysis of data

Each patient episode was analyzed with QCPR-Review software (v2.1.1.0, Laerdal Medical Corporation, Stavanger, Norway). The data from two different HeartStart MRx defibrillators were synchronized by visually plotting the depth waves in Matlab (MathWorks, Natick, MA) and adjusting the delay until a perfect match was achieved, and made available for processing by AnalyzeQCPR (Laerdal Medical AS, Stavanger, Norway). The objective was to match compression-to-compression movement (CC depth) of the upper vs. lower FDS. The upper FDS measured the movement of the chest and the mattress/bed frame together, while the lower FDS measured the compressions of the mattress and the bed frame only. The real CC depth was calculated as the difference between highest point of the total CC depth measured from the upper FDS and the lower FDS.

For basic CPR quality analysis the resuscitation attempts were divided into 1-min epochs. The uniform guidelines for reporting CPR quality were used.¹¹ Chest anterior–posterior diameter and chest circumference were measured immediately after each resuscitation attempt. Patients' height and weight were obtained from medical or autopsy reports. According to earlier animal studies, 25% of each patient's chest anterior–posterior diameter was chosen as one of the individual goals of CC depth.^{12,13}

2.5. Statistical analysis

Statistical analyses were performed using PASW 19.0 software (SPSS Inc., Chicago, IL, USA). Data are presented as numbers and percentages of patients, medians with interquartile ranges (IQR), or as means and standard deviations (SD) depending on the normality of the distribution. Differences between the groups were analyzed using χ^2 -test and Student's *t*-test or Kruskal–Wallis test for continuous data, as appropriate, and $p < 0.05$ was considered statistically significant.

3. Results

Ten patients (out of 74 resuscitated during the study period) were resuscitated with dual-FDS system and comprised the study cohort. We analyzed four CPR attempts on a standard hospital bed (HB), three on emergency room stretchers (ER) and three on the intensive care unit beds (ICU) (Table 1).

A total of 10,868 CCs (246–6398 per patient) were analyzed with dual FDS-system. The results are summarized in Tables 1 and 2. The mean mattress/bed frame deflections were 12.8 (4), 12.4 (4) and 14.1 (3) mm in HB, ER and ICU beds, respectively. Patients in HB had 94% of all CCs within the adequate depth (≥ 50 mm) before any compensation for mattress/bed frame deflection. The proportion of CCs with adequate depth decreased to 64% after compensation ($p < 0.001$). The corresponding figures for ER beds were 98% and 76% ($p < 0.001$), and for ICU beds 91% and 17% ($p < 0.001$).

After compensation for the mattress effect, the proportion of CCs exceeding the individual threshold (CC depth 25% of the each patient's chest anterior–posterior diameter) decreased further (Table 1).

4. Discussion

This is the first clinical investigation to use two FDSs during in-hospital CPR to study the possible overestimation of CC depth. The

Table 2
Effect of bed and mattress type on chest compression depth. Compression depth was measured taking and not taking the mattress/bed deflection into consideration.

	HB (n = 1464)	ER (n = 7311)	ICU (n = 2093)
Total depth (mm)	66 (11)	68 (9)	59 (6)
Mattress/bed deflection effect (mm)	12.8 (4)	12.4 (4)	14.1 (3)
Real CC depth (mm)	53 (9)	55 (7)	44 (6)
Mattress/bed contribution on CC depth (%)	20 (5)	18 (5)	24 (5)
Proportion of CC's with depth >50 mm (%)	94	98	91
Proportion of CC's with real depth >50 mm (%)	64*	76*	17*

The data are given as mean (SD) or percentage. HB, standard hospital bed with gel mattress: Hospital bed Carena (Merivaara Oy, Lahti, Finland); mattress type: Mattress MediForm Safe (Merivaara Oy, Lahti, Finland). ER, emergency room stretcher with standard mattress: Trolley Emergo (Merivaara Oy, Lahti, Finland); mattress type: Standard gel mattress (Merivaara Oy, Lahti, Finland). ICU, intensive care unit bed with air mattress: Hospital bed Carena (Merivaara Oy, Lahti, Finland); mattress type: Air Mattress, Quattro acute (Talley Medical, Hampshire, UK).

* $p < 0.001$ for difference compared to fraction of CC's with depth >50 mm without compensation for mattress/bed frame deflection.

data support the hypothesis that single-FDS systems overestimate CC depth. This implied that most aspects of CPR quality (including CC rate, CC fraction, and full recoil) can be measured and adjusted with single-FDS system but CC depth may be prone to error because of the mattress effect.

Therefore, while the use of single-FDS systems may improve the overall CPR quality, the adequacy of CC depths may be limited or even hampered. A dual-FDS system may allow the clinician to adequately monitor and adjust the compression depth.

In previous manikin studies the mattress/bed frame deflection was even more pronounced even though the manikins were lighter and smaller than the patients in our study.^{3,4} The discrepancies may be due to the lack real-time feedback and/or the use of different types of backboards.^{14,15} It must also be emphasized that a manikin cannot simulate all the characteristics of human subjects.

Our results are in line with previous studies investigating the mattress/bed frame deflection effect in children and in young adults.^{2,16} A recent study by Nishisaki et al.¹⁷ showed that with torso weight of 25 kg vs. 50 kg, the mattress/bed frame deflection was greater. They concluded that backboards may not be needed for CPR on firm stretchers, firm hospital beds, or for patients with heavy torso weights. Herein however, we exemplify adult patients with high body weight who did have marked mattress effect. Therefore, we wish to express our concern on the quality CPR in adult patients over the range of body weights with or without CPR quality measurements. It has been suggested that decrease in CC depth must be at least 5 mm to be clinically significant.¹⁸ In the present study individual values for mattress/bed deflection varied between 10 and 15 mm in seven out of the 10 patients, which demonstrates the general tendency of single-FDS to overestimate the depth of CC when performed on a bed. In animal models CC depths at least 25% of the chest anterior–posterior diameter are associated with high ROSC rate.^{12,13} In the present study CC depth exceeding 25% of diameter was achieved in 60% of the uncompensated compressions and in only 10% of the compensated compressions.

Currently the use of dual-FDS system with real-time corrected CC depth is not clinically available. While technical solutions are on the way to clinics¹⁹ it should be reasonable to adjust towards deeper CC instead of shallower when CPR is performed on a compliant surface.²⁰ Potential for CPR related trauma may need to be considered in conjunction.⁹

The small number of patients and the observational design may limit the interpretation of the result herein. However, the results

encourage to vigilance over individual CPR patients and the quality of CPR according to guidelines.

In this study CC depth was guided by real-time audiovisual feedback from the defibrillator, but also by utilizing clinical signs and multiple monitors as available for each patient. Consequently, our data do not conclusively report the incidence of overestimation of CC depth with a single-FDS system. Meanwhile, the CC depth gradient, that is the extent of mattress effect over the range of body weights and bed type is alerting. This alone is the single most important message from our study.

Chest anterior–posterior diameter, measured for each patient following CPR, may be biased if there were chest trauma induced by CPR. This would be associated with decreased minimal ideal threshold for effective CC depth. Therefore, we suggest that overestimation of CC depths does occur even when compared to theoretical ideal compression depth.

5. Conclusions

Single-FDS system and real-time compression feedback feature overestimate the CC depths delivered on a compliant surface (such as bed) in clinical practice. The results should alert the clinicians to vigilance over individual patient's CPR quality.

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Conflict of interest statement

Joar Eilevstjønn is employed by Laerdal Medical AS, Stavanger, Norway. Sanna Hoppu has provided paid consultancy for Laerdal Medical Corporation. Jyrki Tenhunen has been a member of international advisory board for SuPARnostic (Virogates, Copenhagen, Denmark) and is co-founder and shareholder in SenSem Technologies Ltd (Tampere, Finland) and Medieta Ltd (Helsinki, Finland). Laerdal Medical has not funded any part of this study. The other authors have no conflicts of interest to declare.

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PUBLICATION IV

Deeper chest compression - more complications for cardiac arrest patients?

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Clinical paper

Deeper chest compression – More complications for cardiac arrest patients?☆

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ABSTRACT

Aim of the study: Sternal and rib fractures are frequent complications caused by chest compressions during cardiopulmonary resuscitation (CPR). This study aimed to investigate the potential association of CPR-related thoracic and abdominal injuries and compression depth measured with an accelerometer.

Methods: We analysed the autopsy records, CT scans or chest radiographs of 170 adult patients, suffering in-hospital cardiac arrest at the Tampere University Hospital during the period 2009–2011 to investigate possible association of chest compressions and iatrogenic injuries. The quality of manual compressions during CPR was recorded on a Philips, HeartStart MRx Q-CPR™-defibrillator.

Results: Patients were 110 males and 60 females. Injuries were found in 36% of male and 23% of female patients. Among male patients CPR-related injuries were associated with deeper mean – and peak compression depths ($p < 0.05$). No such association was observed in women. The frequency of injuries in mean compression depth categories <5 , 5 – 6 and >6 cm, was 28%, 27% and 49% ($p = 0.06$). Of all patients 27% sustained rib fractures, 11% sternal fracture and eight patients had haematomas/ruptures in the myocardium. In addition, we observed one laceration of the stomach without bleeding, one ruptured spleen, one mediastinal haemorrhage and two pneumothoraxes.

Conclusion: The number of iatrogenic injuries in male patients was associated with chest compressions during cardiopulmonary resuscitation increased as the measured compression depth exceeded 6 cm. While there is an increased risk of complications with deeper compressions it is important to realize that the injuries were by and large not fatal.

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1. Introduction

Ever since Peter Safar developed cardiopulmonary resuscitation (CPR) in the 1960s, there has been discussion about iatrogenic injuries associated with chest compressions.^{1–4} Sternal and rib fractures are frequent complications of chest compressions^{4–7} but sometimes CPR can result in intra-thoracic or intra-abdominal lacerations and haemorrhage which may even prove fatal.^{8,9}

The European Resuscitation Council (ERC) published new guidelines for resuscitation in 2010. High quality chest compressions are an essential part of these guidelines. Compression depth should be 5–6 cm and the rate at least 100 compressions per minute.^{10–12} It

has been suggested that an increased compression depth may be associated with a higher incidence of iatrogenic injuries. Although there are studies on CPR-related injuries in adults and infants,^{13–15} none of them has investigated the potential association between the actual compression depth as measured with the accelerometer and the incidence and severity of complications after CPR. The purpose of this study was to investigate a possible association between CPR-related thoracic and abdominal injuries and objectively measured compression depth. Our hypothesis was that the risk of injuries increases as the compression depth increases.

2. Methods

2.1. Study design

This observational study was performed under approval of the Pirkanmaa Hospital District's Science Center and the Ethics

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Committee of the Tampere University Hospital (Approval no: R08116; clinicaltrials.gov NCT00951704). Data from the resuscitations were collected prospectively as a part of our on-going studies on the quality of resuscitation and also for educational purposes. The injuries were analysed retrospectively from the autopsy reports and thorax/CT-scans. Authorization to analyse forensic autopsy findings was requested from the National Institute for Health and Welfare and Regional State Administrative Agencies.

2.2. Source population

From 1.1.2009 to 31.12.2011 all adult patients, resuscitated by Medical Emergency Team (MET) in Tampere University Hospital, were considered for inclusion to the study. The quality of chest compressions was recorded during resuscitation and compared to chest/upper abdomen CT-scan or chest radiography done during post-resuscitation care. The attending physician decided if and when a CT-scan or thorax X-ray was needed on the basis of the patient's clinical condition. Patients whose resuscitation proved unsuccessful were autopsied and the findings were correlated to the quality details of CPR. The need for forensic autopsy is stipulated in the Finnish legislation and therefore forensic autopsies were not performed as a part of the study protocol. Medical autopsies were performed when the cause of death was uncertain or the attending physician thought that the cause of death had to be confirmed. Exclusion criteria were resuscitation prior to hospital admission, preresuscitation trauma in the thoracic or abdominal area, or use of a load-distributing band device (Autopulse™) during attempted resuscitation.

2.3. Hospital and MET

Tampere University Hospital is a tertiary referral centre with 800-acute-care-beds for a base population of 1,200,000 and 71,000 patient admissions/year. The incidence of sudden cardiac arrests (SCA) was approximately 2.2/1000 hospital admissions annually during the period 2009–2011.

MET was implemented in 2009. The MET consists of two intensive care unit (ICU) nurses and an intensivist on-call. The purpose of the team is to facilitate early recognition of patients in risk of clinical deterioration, but as a part of the hospital protocol, MET is also called to take care of sudden cardiac arrest (SCA) victims and ensure that resuscitation attempt is performed according to ERC guidelines. Most of the SCA patients at Tampere University Hospital are treated by MET.

2.4. Defibrillator and data from the resuscitation

Alongside the standard resuscitation equipment and emergency medicines, the MET is equipped with a Philips HeartStart MRx defibrillator (Philips, Eindhoven, Netherlands) with a CPR quality (Q-CPR, Laerdal Medical, Stavanger, Norway) analysis feature.^{16,17} The CPR quality parameters used in this study were average compression depth, peak compression depth, peak force, episode length and number of compressions per episode. Resuscitations were analysed in 30 s epochs/fractions. The deepest single peak compression depth and the highest peak force during the whole resuscitation attempt were extracted directly from Q-CPR review software by a member of the research team.

Detailed information on the quality of chest compressions during resuscitation attempts was stored on a memory card and then transferred to a laptop and processed and analysed with Q-CPR Review software (v2.1.1.0. Laerdal Medical Corporation, Stavanger, Norway).

2.5. Injuries related to chest compressions and patients' medical history

Injuries related to chest compressions were analysed retrospectively from the forensic autopsy records and medical autopsy records. One radiologist analysed patients' injuries from CT findings and chest radiographies by re-evaluating them retrospectively blind to resuscitation quality data. Injuries, interpreted to have been caused by CPR, were sternal and rib fractures, haematomas associated with rib fractures, anterior mediastinal haemorrhage, pneumothorax, haemothorax, contusion/laceration/bruising of lung and heart, injuries to great veins or aorta and laceration/rupture of spleen, liver or stomach. Prior medical histories, age and BMI were obtained from the medical records of each patient. We recorded information on possible osteoporosis, hyperparathyroidism, rheumatoid arthritis, chronic renal failure and diabetes mellitus as well as long-term use of corticosteroids (inhaled or oral) and consumption of alcohol or tobacco.

2.6. Statistical analysis

Statistical analyses were performed with IBM SPSS Statistics for Windows (SPSS Version 19.0. Armonk, NY: IBM Corp.). Comparisons of continuous data were done with independent samples *t*-test or Mann–Whitney *U*-test as appropriate. Binomial variables were analysed with χ^2 -test. The data are presented as a percentages and numbers of patients, as medians with interquartiles (IQR), or as means and standard deviations (SD) as appropriate. Two-sided $p < 0.05$ was considered statistically significant.

3. Results

3.1. Injuries in the whole study population

Of the 370 patients resuscitated by MET a total of 170 SCA patients were included in this study. A flowchart of the patients is shown in Fig. 1. Of all the patients 32% ($n=54$) had sustained injuries. When these injuries were analysed year by year, the incidence of injuries during the three-year period was 25%, 32% and 40% respectively ($p=0.21$). The incidence of injuries in patients subjected to forensic autopsy, was 30%, 42% and 64% in 2009, 2010 and 2011, respectively ($p=0.03$). Injuries are reported in detail in Table 1.

In the three-year period the mean compression depth in patients sustaining CPR-related injuries was 56 mm compared to 52 mm ($p=0.04$) in patients without injuries. When the mean compression depth was divided into three categories (<50 mm, 50–60 mm and >60 mm), there was an increase in the frequency of injuries of 28%, 27% and 49% in the three groups respectively ($p=0.06$). The details of the resuscitation attempts are presented in Table 2. In 2011 new resuscitation guidelines were implemented. After the implementation, the mean compression depth in the injured group of patients was 63 mm compared to 55 mm ($p=0.002$) in patients without injuries. Association between compression depth and injuries on a yearly basis are shown in Fig. 2.

In the three-year period the peak compression depth was also significantly deeper in patients who sustained injuries, 77 mm vs. 70 mm ($p=0.003$). After the implementation of new the guidelines a similar association between peak compression depth and injuries was seen as between mean compression depth and injuries. In injured patients the peak compression depth was 86 mm vs. 73 mm in patients without injuries ($p=0.001$) (Fig. 3).

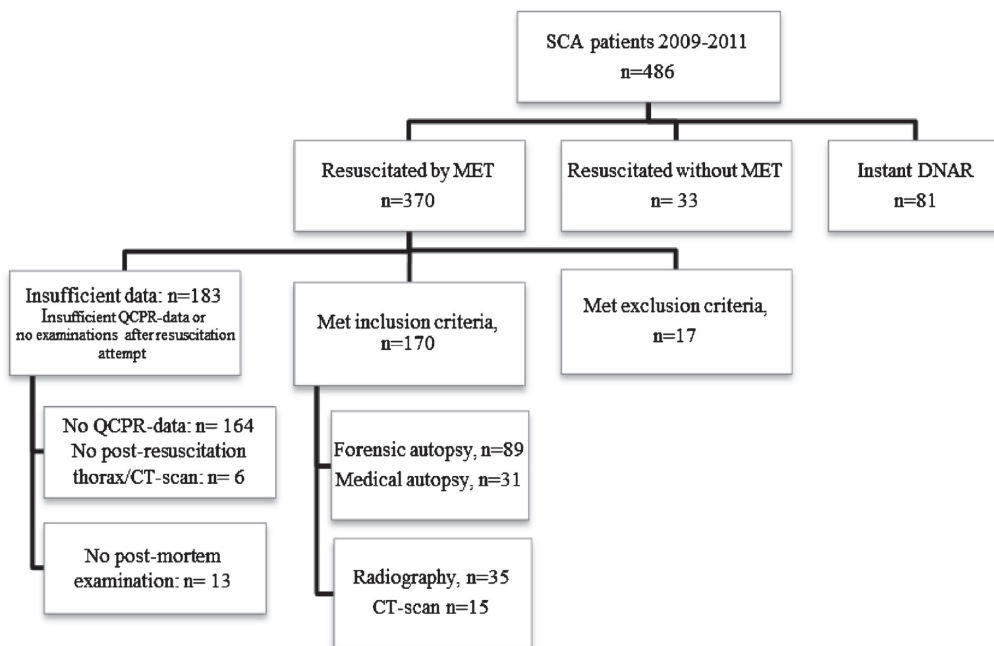


Fig. 1. Flowchart of the patients, years 2009–2011.

3.2. Injuries analysed by gender

Of the patients suffering complications 40/54 (74%) were male. Men appeared to sustain slightly more rib (31% vs. 20%) and sternal (11% vs. 9%) fractures than women but these differences were not statistically significant. Patients with more than nine fractured ribs were all men. Details of the resuscitation attempts divided by gender and groups of injured and non-injured are presented in Table 3.

In male patients, the frequency of injuries was 29%, 33% and 63% in mean compression depth categories <50 mm, 50–60 mm and >60 mm respectively ($p=0.03$), and in categories of <60 mm and >60 mm the percentages were 31% and 63% ($p=0.008$). Resuscitation attempts on male patients lasted longer than on female patients. No association was found between medications, prior medical history and injuries.

In female patients both peak compression depth (74 vs. 71 mm) and mean compression depth (55 vs. 52 mm) tended to be greater

Table 1
Injuries associated with chest compressions.

		All patients n = 170 n (%)	Male n = 110 (65) n (%)	Female n = 60 (35) n (%)
Thorax	Rib fracture	41/153 (26.8)	30/97 (30.9)	11/56 (19.6)
	Single		7	3
	Multiple		23	8
	Sternal fracture	16/153 (10.5)	11/97 (11.3)	5/56 (8.9)
	Haematoma – rib fractures	11/41 (26.8)	7/80 (8.8)	4/52 (7.7)
	Mediastinal haemorrhage	1 (0.8)	0	1/49 (2.0)
	Pneumothorax	2/168 (1.2)	2/110 (1.8)	0
	Haemothorax	0	0	0
Lung	Contusion – lung	1/134 (0.7)	0	1/51 (2.0)
Heart and great vessels	Haematoma/rupture – heart	8/127 (6.3)	6/80 (7.5)	2/47 (4.3)
	Posterior haematoma	3	2	1
	Rupture	5	4	1
	Great vessels	2/126 (1.6)	2/79 (2.5)	0
Abdomen	Liver rupture	0	0	0
	Spleen rupture	1/125 (0.8)	1/78 (1.3)	0
	Gastric rupture	1/125 (0.8)	0	1/47 (2.1)

The injuries are presented as number and percentage of patients. Number of patients in each injury category varies on the basis of injury detection method.

Table 2
Baseline resuscitation characteristics.

Annual characteristics	2009	2010	2011
n (%)	61 (36)	54 (32)	55 (32)
Episode length (min)	10:21 (05:57, 15:54)	05:33 (03:43, 13:35)	8:55 (03:47, 15:53)
Compression/episode (n)	984 (589, 1568)	541 (361, 1293)	815 (314, 1487)
Mean compression depth (mm)	47 (44, 53)	51 (45, 58)	55 (53, 64)
Peak compression depth (mm)	69 (11)	70 (11)	78 (13)
Peak force (kg)	51 (11)	55 (11)	60 (12)
Injuries, n (%)	15 (25)	17 (32)	21 (38)

The data are presented as medians (IQR) or as means (SD).

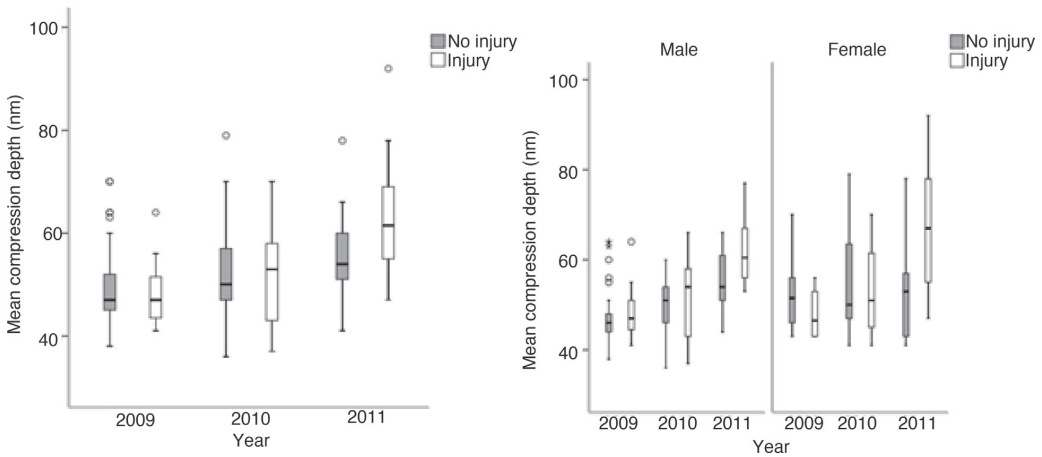


Fig. 2. Mean compression depth by year and injury.

than in male patients but these differences were not statistically significant. No association was found between mean or peak compression depth and injuries in women before implementation of the new guidelines and after the implementation; only the peak compression depth was significantly deeper among injured women, 93 mm vs. 72 mm in non-injured women ($p = 0.02$). The median age

of injured women was lower than among uninjured women, 67 vs. 76 years ($p = 0.036$). The use of cortisone and cigarette smoking were associated with a higher number of injuries ($p = 0.03$) but there was no association between BMI and frequency of injuries. Interestingly, the likelihood of resuscitation injuries was not associated with compression force in either gender.

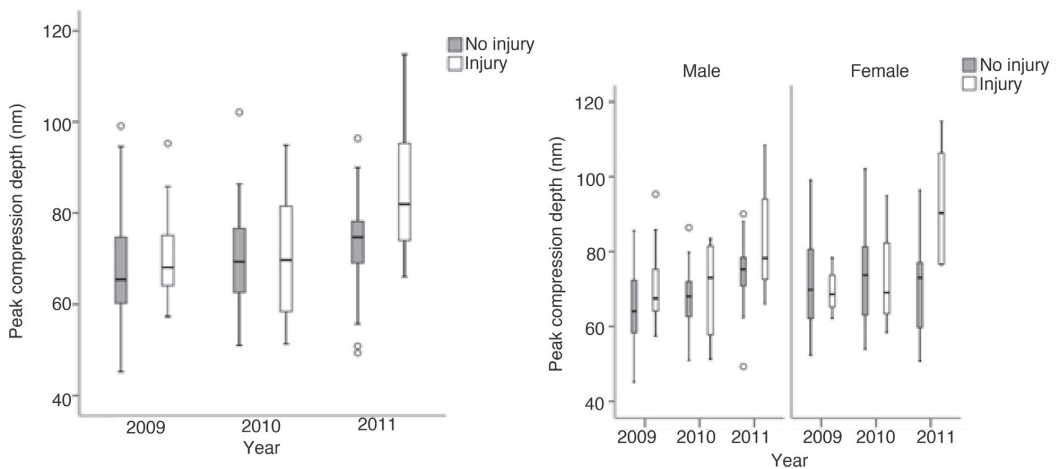


Fig. 3. Association between peak compression depth and injuries on a yearly basis.

Table 3
Resuscitation and patient characteristics divided into injured and non-injured groups.

Variables	Study population, n = 170			Male, n = 110 (65)			Female, n = 60 (35)		
	No injuries	Injuries	p-value	No injuries	Injuries	p-value	No injuries	Injuries	p-value
n (%)	117 (69)	53 (31)		70 (64)	40 (36)		46 (77)	14 (23)	
Age	72 (64, 80)	72 (56, 77)	0.32	68 (63, 77)	73 (61, 78)	0.63	76 (65, 82)	67 (53, 77)	0.04
BMI	31 (8)	32 (12)	1.00	30 (7)	31 (6)	0.47	33 (10)	28 (6)	0.95
Episode length (min)	07:37 (03:43, 13:13)	09:37 (04:51, 18:30)	0.04	07:26 (04:21, 15:51)	11:17 (04:44, 18:42)	0.25	07:37 (02:37, 12:28)	08:17 (07:19, 15:38)	0.22
Compression/episode	723 (326, 1305)	915 (438, 1735)	0.07	763 (379, 1416)	962 (419, 1740)	0.34	656 (244, 1287)	883 (683, 1616)	0.17
Mean compression depth (mm)	52 (8)	56 (11)	0.04	51 (7)	55 (10)	0.02	56 (10)	59 (16)	0.52
Peak compression depth (mm)	70 (11)	77 (14)	0.003	69 (10)	75 (13)	0.006	75 (14)	82 (18)	0.26
Peak force (kg)	54 (12)	58 (12)	0.10	56 (11)	59 (11)	0.24	51 (13)	53 (12)	0.56

The data are presented as number and percentage of patients, as medians (IQR), or as means (SD).

3.3. Survival among injured patients

The percentage of immediate and short-term survival was not affected by a greater number of CPR-related injuries when analysed on a yearly basis.

4. Discussion

This is the first clinical study to suggest an association between increasing compression depth and injuries related to chest compressions during CPR. The majority of the injuries in the present study were spontaneously healing fractures and the frequency of the injuries was comparable to those reported in earlier studies.^{7,15} Life-threatening ruptures of the myocardium were detected only in patients with acute myocardial infarction. It is very difficult to establish the causality between myocardial rupture in the infarcted area of the heart and chest compressions during CPR. Nevertheless, without CPR, the patients would have died from the arrhythmia. In this study all the patients, with unsuccessful resuscitation attempt, died due to other reasons than CPR related injuries and none of the injuries contributed to the deaths of the patients.

The injuries of interest in this study were detected from the forensic and medical autopsy reports, conventional chest X-rays and CT-scans. The findings in the forensic autopsy reports show a higher percentage of injuries than all other investigation methods combined. Chest X-rays and CT-scans do not reveal as much information as autopsies. Some of the haematomas and fractures may go undetected. As Kim et al. and Lederer et al. stated in their studies, conventional chest X-rays do not detect all the rib and sternal fractures.^{4,19} Almost a third of the patients in our study were examined by CT-scan or X-ray, so there is a possibility that some of the CPR-related injuries went undetected.

According to earlier studies, female patients are more susceptible to CPR-related injuries.^{6,15,18} Interestingly, in our study male gender was associated with a higher rate of injuries than female gender, although the peak compression depth and mean compression depth were greater in resuscitation attempts on female patients. Indeed, there are uncertainties in some of the variables recorded with the accelerometer. The so-called mattress effect is caused by the compliant surface beneath the patient. The force used to compress the chest of the patient also compresses the mattress and therefore the accelerometer shows the whole movement as a chest compression depth. Because female patients may be smaller than male patients, the mattress effect may be more pronounced in women causing more bias in recordings from female patients. Furthermore, the accelerometer does not take account of the individual properties (such as compliance and elasticity) of each patient's bony rib cage, neither does it recognize the possible oblique angle of chest compression to the sternum and rib cage which may cause an uneven distribution of the compression and force applied.

Although deeper compressions were associated with greater risk of injuries in men in the present study, they are also associated with a higher success rate of defibrillation and ROSC.^{20,21} Deeper compression depth also improves survival.²² However, we must be aware of the increased risk of injuries associated with deeper compressions. Exaggerated fear of injuries related to deeper compression depth could potentially lead to a reduction of compression depths below the recommendation.²³ With QCPR-technology we can monitor and also improve the quality of CPR.^{24–26} Still to date we do not know the exact and ideal depth of chest compressions. With automated feedback devices we can optimize the quality of CPR and decrease the number of very deep compressions and keep the mean compression depth as close to the

recommendations as possible which will help us to avoid critical injuries to patients.

5. Limitations of the study

This study has a number of limitations. First, we do not know the quality of chest compressions during the short resuscitation attempt before MET has arrived and started to use the sternal force/depth sensor. Second, even though all resuscitations were performed using a backboard to decrease the mattress effect, there is no technology available to enable us to know the absolute compression depth in all cases. Yet we have to bear in mind that all the earlier studies about sufficient compression depth and the effects of compression depth have been made on different surfaces and are therefore not entirely comparable. This study is based partly on patient records. In some cases patient records were unavailable or lacked information, which may hamper the risk factor analysis of the study. It is important to remember that more than half of the patients considered for resuscitation by MET were not included due to missing Q CPR data which might have biased the interpretation of the data. The main reason for missing data was human error in saving of the data.

6. Conclusions

The number of iatrogenic injuries in male patients due to chest compressions during cardiopulmonary resuscitation increased as the compression depth exceeded 6 cm. No such association was seen in female patients. The majority of the injuries was spontaneously healing rib fractures or haematomas having only a minor impact on patients' recovery from resuscitation. While there is an increased risk of complications with deeper compressions it is important to realize that the injuries were by and large not fatal.

Conflicts of interest statement

This study was funded by the Instru Science Foundation, Helsinki, Finland and by the Competitive Research Funding of the Tampere University Hospital (Grant 9M105). The funding organizations had no involvement in any aspect of the study.

Dr. Jyrki Tenhunen is a member of international advisory board for SuPARnostic (Virogates, Copenhagen, Denmark) and CMO and shareholder of SenSem Technologies (Tampere, Finland) and Medietta Ltd (Helsinki, Finland).

Dr. Sanna Hoppu has provided paid consultancy for Laerdal Medical Corporation. Laerdal Medical has not funded any part of this study, nor had access to any of the data or part taken in the process of the study.

The other authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.resuscitation.2013.02.015>.

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PUBLICATION V


Good quality of life before cardiac arrest predicts good quality of life after resuscitation

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Good quality of life before cardiac arrest predicts good quality of life after resuscitation

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Conflict of interests

Dr. Jyrki Tenhunen has been a member of the SuPAR-Symposium organizing committee for SuPARnostic (Virogates, Copenhagen, Denmark) and co-founder and shareholder of SenSem Technologies (Tampere, Finland) and Medieta Ltd (Helsinki, Finland). The other authors declare no conflicts of interest.

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Background: The survival rate of cardiac arrest patients is increasing. Our aim was to compare the quality of life before and after cardiac arrest and analyse the factors associated with outcome.

Methods: All adult cardiac arrest patients admitted to the Tampere University Hospital intensive care unit between 2009 and 2011 were included in a retrospective follow-up study if surviving to discharge and were asked to return a questionnaire after 6 months. Data on patient demographics and pre-arrest quality of life were retrieved from medical records. Data are given as means (SD) or medians [Q₁, Q₃]. We used logistic regression to identify factors associated with better quality of life after cardiac arrest.

Results: Six months after cardiac arrest, 36% (79/222) were alive and 70% (55/79) of those patients completed the follow-up Euro-QoL (EQ-5D) quality of life questionnaire. Median values for the EQ-5D before and after cardiac arrest were 0.89 [0.63, 1] and 0.89 [0.62, 1], respectively ($P = 0.75$). Only the EQ-5D prior to cardiac arrest was associated with better quality of life afterwards (OR 1.2; 95% CI 1.0–1.3; $P = 0.02$).

Conclusions: Quality of life remained good after cardiac arrest especially in those patients who had good quality of life before cardiac arrest.

Editorial comment

Quality of life is an important clinical outcome. The report presents a highly selected sample of cardiac arrest survivors who assessed their quality of life after survival. This was compared to the patients' retrospective assessment of quality of life prior to the arrest. Most reported unchanged quality of life after the incident.

Although the survival rate of cardiac arrest (CA) patients may be increasing at least in expert centres, wide variation between centres persists.¹

Reports suggest that cardiac arrest survivors have good or at least acceptable quality of life.^{2–6} Factors predicting better survival at hospital discharge and

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good quality of life are ventricular fibrillation (VF) as an initial rhythm and short delay to the return of spontaneous circulation (ROSC).⁷

Quality of life is a complex and multidimensional term based on four different elements, namely socioeconomic factors, health and ability to function in daily living, self-awareness and life satisfaction.⁸ The term "health-related quality of life" was coined for research purposes, comprising mental, physical and social components of well-being.^{9,10} Numerous different scales can measure quality of life,^{11–13} many of which have been used to analyse quality of life after CA.² In the 1990s, the EuroQoL Group developed a quality of life questionnaire based on five domains of everyday living and self-care.¹⁰ The EuroQoL 5D (EQ-5D) has also been used to report CA patients' quality of life.^{13–15} The quality of life index (EQIndex) is calculated from the scores of the five domains given by the patient. The range of the score varies from 0 to 1, 1 being the best possible quality of life.

This study was aimed to assess the quality of life before and 6 months after CA using the EQ-5D questionnaire as a health-related quality of life scale (primary endpoint). We also wanted to identify possible factors associated with good quality of life (secondary endpoint).

Methods

Study design

This retrospective observational study was approved by Pirkanmaa Hospital District Science Center and the Ethics Committee of Tampere University Hospital (Approval no: R08116, 22.2.2011; clinicaltrials.gov NCT00951704). Data on the EQ-5D questionnaire before and after CA, medical histories, cause of CA, initial rhythm, ROSC, the possible use of therapeutic hypothermia (TH), other treatments or procedures undertaken [e.g. coronary artery bypass graft (CABG) surgery, percutaneous coronary intervention (PCI), or implantable cardioverter-defibrillator (ICD)/cardiac pacemaker implanted] were collected retrospectively from patients' medical files. Charlson's weighted index of comorbidities (CCI)¹⁶ and estimated 10-year survival percentages prior to the CA were calculated using the medical histories.

Source population

From 1.1.2009 to 31.12.2011, we screened all adult patients admitted to intensive care unit (ICU) after successful resuscitation from in-hospital cardiac arrest (IHCA) or out-of-hospital cardiac arrest (OHCA). Those successfully resuscitated and alive 6 months after resuscitation received the EQ-5D questionnaire by mail, and patients who responded to the follow-up EQ-5D questionnaire constituted the study population.

Hospital and intensive care unit

Details of Tampere University Hospital (TAUH) and incidence of IHCA have been published in our previous study.¹⁷ The incidence of OHCA in the Tampere region is 52/100,000.¹⁸ The mixed ICU has 22 beds, 12 primarily reserved for critically ill patients. The remaining beds provide a high dependency unit with special monitoring and treatment for patients with single organ dysfunction.

Health-related quality of life, Charlson's weighted index of comorbidities

Quality of life before and after resuscitation was measured on the EQ-5D questionnaire, with five dimensions of quality of life (mobility, self-care, usual activities, pain/discomfort and anxiety/depression) assessed in one simple score (EQIndex). The version of the EQ-5D questionnaire used in this study has three grades of problems in each dimension describing quality of life: no, some and major problems.¹¹ A score of one equals full health and zero equals death in the EQIndex. A change of 0.05 points is considered significant. The second part of the questionnaire is a self-rated visual analogue scale (VAS) ranging from 0 to 100, 100 being the best possible overall health. In this study, VAS was omitted from the analysis due to missing data. All patients admitted to ICU were interviewed with EQ-5D questionnaire upon arrival or later during their stay depending on the condition of the patient to obtain the pre-incident quality of life measurement. If the patient was too sick to respond, the next of kin served as a reliable proxy.^{19,20} Therefore, the EQ-5D questionnaire

was chosen as a method to report quality of life after CA.

The CCI was used to characterize the burden of diseases. Predetermined International Classification of Diseases diagnosis codes were used to calculate CCI.¹⁶ Charlson's index has been shown to predict hospital mortality in critically ill patients and also 1-year survival.^{21–24} The CCI is also used to calculate the estimated 10-year pre-incident survival percentage.²⁵

Statistical analysis

IBM SPSS Statistics for Windows (SPSS Version 22.0.; IBM Corp., Armonk, NY, USA) was used for the statistical analyses. The independent sample *t*-test and Mann–Whitney *U*-test were used for comparison of continuous data, and paired EQIndexes were analysed using the Wilcoxon test. Binomial variables were analysed with the chi-square test. EQIndex after CA was dichotomized from 0.885 into two equal-sized groups. Forward stepwise binary logistic regression was used to explain higher post-

resuscitation EQIndex using initial rhythm (VF vs. asystole/pulseless electrical activity); CCI; ROSC (min); TH; age; PCI/CABG; and EQIndex before CA as explanatory variables. Results are shown as percentages and numbers of patients, as medians with interquartile range [Q₁, Q₃], or as means with standard deviations (SD) as appropriate. Results for the binary logistic regression analyses are shown as odds ratios (OR) and 95% confidence intervals (95% CI). Two-sided *P* < 0.05 was considered statistically significant.

Results

Patients' demographics

During the study period, a total of 222 patients received post-resuscitation care in the ICU. After 6 months, 79/222 (36%) were alive, and 55/79 (70%) made a post-discharge follow-up visit to the ICU or replied by mail to the EQ-5D questionnaire. A flow-chart of the patients admitted to ICU is presented in Fig. 1.

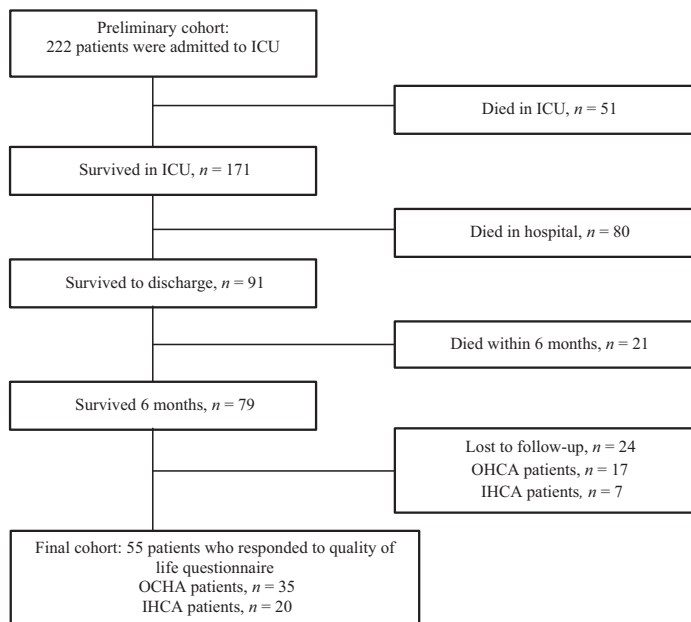


Fig. 1. Flowchart of the patients.

Patients' mean age was 66 (14) years, and 42/55 (76%) were male. The percentages of CCI were 0: 33%, 1–2: 48%, ≥ 3 : 19%. Fifty-six percent of all patients had a pre-incident estimated survival of 10 years, estimated by the CCI. ROSC was achieved in 13 [8, 25] min. TH was used for 28 (51%), CABG/PCI was done for 15 (27%), and ICD/pacemaker was implanted for 17 (31%) patients. There were no statistical differences regarding age, gender dispersion, number of comorbidities, estimated 10-year survival, EQIndex prior to CA, or time to ROSC between patients who answered to the questionnaire and patients who did not. Patients' characteristics are shown in Table 1.

Out-of-hospital cardiac arrest patients represented 64% (35/55) of the study population. In OHCA patients, ROSC was achieved in 19 min [11.0, 31.0], whereas in IHCA patients, it was achieved in 7.5 min [5.25, 12.25] ($P < 0.001$). OHCA patients had less comorbidities than IHCA patients ($P = 0.04$), and 64% of the OHCA patients were estimated to survive 10 years, whereas the corresponding percentage for IHCA patients was 41% ($P = 0.02$). Therapeutic hypothermia was used for 66% of OHCA

and 25% of IHCA patients ($P = 0.004$). A similar difference was also seen in revascularization procedures: 14/35 (40%) of OHCA patients had either PCI or CABG, but only 1/20 (5%) of IHCA patients underwent CABG ($P = 0.005$).

Details of these patient/treatment groups are shown in Table 1. We observed no statistically significant differences in the quality of life, gender, or age between the cardiac patients treated with a revascularization procedure or TH and those who were not.

Quality of life

The values for the EQIndex for all the patients before and after CA were 0.89 [0.63, 1] and 0.89 [0.62, 1] ($P = 0.75$), respectively. Pre- and post-CA quality of life parameters are shown in Table 2.

Table 3 presents the results from the binomial multivariable logistic regression model assessing the association between post-CA EQIndex and possible predictive factors. Higher EQIndex values prior to CA were associated with increased odds of higher EQIndex post-CA (OR 1.2; 95% CI 1.0–1.3; $P = 0.02$). Subgroup

Table 1 Characteristics of the patients.

Variables	Study population <i>n</i> = 55 (%)	IHCA <i>n</i> = 20 (36)	OHCA <i>n</i> = 35 (64)	<i>P</i> -value
Age	68 [60, 77]	72 [64, 80]	65 [60, 73]	0.11
Gender, male (%)	42 (76)	14 (70)	28 (80)	0.51
CCI (%)				
Index value 0	18 (33)	4 (20)	14 (40)	0.04
Index value 1–2	26 (48)	9 (45)	17 (49)	0.05
Index value ≥ 3	11 (19)	7 (35)	4 (11)	0.68
Estimated 10 years survival (%)	56 (33)	41 (36)	64 (29)	0.02
Pre-CA EQIndex	0.89 [0.63, 1]	0.85 [0.63, 0.92]	0.89 [0.72, 1]	0.36
Post-CA EQIndex	0.89 [0.62, 1]	0.85 [0.62, 0.92]	0.89 [0.71, 1]	0.34
ROSC, min	13 [8.0, 25.0]	7.5 [5.3, 12.3]	19.0 [11.0, 31.0]	< 0.001
TH (%)	28 (51)	5 (25)	23 (66)	0.004
Revascularization (%)	15 (27)	1 (5)	14 (40)	0.005
ICD/PAMA (%)	17 (31)	3 (15)	14 (40)	0.05
Cause of CA				
Cardiac origin (%)	37 (67)	8 (40)	29 (83)	0.001
Non-cardiac origin (%)	18 (33)	12 (60)	6 (17)	0.001
Initial rhythm				
Shockable rhythm (%)	36 (65)	6 (30)	30 (86)	< 0.001
Non-shockable rhythm (%)	19 (35)	14 (70)	5 (14)	< 0.001

CCI, Charlson's weighted index of comorbidities; ICD, implantable cardioverter-defibrillator; IHCA, in-hospital cardiac arrest; OHCA, out-hospital cardiac arrest; TH, therapeutic hypothermia.

Table 2 Quality of life index prior to cardiac arrest and 6 months after cardiac arrest.

Variables	Pre-CA EQIndex	Post-CA EQIndex	P-value
All patients, n = 55	0.89 [0.63, 1]	0.89 [0.62, 1]	0.75
OHCA patients, n = 35	0.89 [0.72, 1]	0.89 [0.71, 1]	0.19
IHCA patients, n = 20	0.85 [0.63, 0.92]	0.85 [0.62, 0.92]	0.24
Cause of CA			
Cardiac, n = 37	0.89 [0.75, 1]	0.89 [0.78, 1]	0.62
Other reason, n = 18	0.61 [0.57, 0.85]	0.72 [0.45, 0.92]	0.75
Initial rhythm			
Shockable rhythm, n = 36	0.89 [0.78, 1]	0.89 [0.81, 1]	0.22
Non-shockable rhythm, n = 19	0.63 [0.56, 0.89]	0.75 [0.45, 0.92]	0.68
Therapeutic hypothermia			
Yes	0.89 [0.63, 1]	0.89 [0.75, 1]	0.35
No	0.81 [0.70, 0.92]	0.89 [0.53, 0.92]	0.59
Revascularization			
Yes	0.89 [0.81, 1]	1 [0.92, 1]	0.91
No	0.89 [0.70, 1]	0.89 [0.81, 1]	0.69

IHCA, in-hospital cardiac arrest; OHCA, out-hospital cardiac arrest; The data presented as medians [Interquartiles]; EQIndex: Quality of life Index (0–1).

analysis of patients with cardiac reasons and non-cardiac reasons yielded similar results.

Discussion

This study demonstrates that in survivors responding to the questionnaire, the overall quality of life after CA is comparable to their retrospective assessment of their pre-CA quality of life. Our results concur with earlier reports, although direct comparisons are difficult due to differences in quality of life scales and because many studies have not considered pre-CA quality of life.^{2–6} Quality of life prior to CA remained the only significant factor predicting better quality of life after CA. Interestingly, patients surviving CA seemed to have a better quality of life before and after CA than their peers in the general Finnish population.²⁶

Table 3 Association of different variables with post-CA EQIndex

Variable	Univariable regression	
	OR (95% CI)*	P-value
Pre-CA EQIndex	1.2 (1.0–1.3)	0.02
Age, year	1.1 (0.9–1.2)	0.09
CCI	1.2 (0.6–2.6)	0.62
Initial rhythm, VF or PEA/ASY	0.6 (0.2–1.9)	0.25
ROSC (min)	1.1 (0.9–1.1)	0.11
Revascularization (PCI/CABG)	2.2 (0.3–2.9)	0.38
Therapeutic hypothermia YES NO	1.1 (0.8–3.1)	0.09

CABG, coronary artery bypass graft; CCI, Charlson's weighted index of comorbidities; PCI, percutaneous coronary intervention; ROSC, return of spontaneous circulation; VF, ventricular fibrillation; *Odds ratio with 95% confidence interval.

Research has shown that OHCA patients presenting with VF as initial rhythm have the best prognoses for survival and good quality of life.^{27–30} In our study, the EQIndex values were similar before and after CA in VF patients. Patients with VF had higher EQIndex values after CA than patients presenting with pulseless electrical activity/asystole. However, VF patients had higher EQIndex values than the others already prior to CA.

In a study published by Bergum et al.,³¹ cardiac causes explained 60% of all IHCA cases, and 30% of discharged patients had a cardiac cause for CA. Less than half of surviving IHCA patients had a cardiac cause for CA, and non-shockable rhythms predominated in the IHCA patients. However, the question remains whether all cardiac patients at risk for CA are properly identified in hospital. Although the patients are of similar age, many diseases are overrepresented in IHCA patients, and the estimated 10-year survival is lower in IHCA than in OHCA patients. The majority of IHCA patients had a comorbidity index of 2 or more predicting increased mortality following intensive care.²⁴

Callaway et al.³² reported in 2014 that early coronary intervention and induced hypothermia were associated with favourable functional status measured with modified Rankin Score in OCHA patients. However, this study lacks the vital information on the patients' functional status prior to CA. A subgroup analysis in our study showed that patients selected for invasive cardiac procedures were associated with higher EQIndex

after CA compared to those without invasive cardiac procedures. No difference was seen in pre-CA EQIndexes, but the patients selected for TH had a higher EQIndex and a lower CCI before CA than patients treated without TH. The patients treated with TH had no change in EQIndex after CA, but the patients treated with conservative methods had a better EQIndex after than before CA. However, when all possible factors influencing the outcome were considered, the only factor which demonstrably predicted better quality of life after CA in the multivariate analysis was good quality of life prior to CA. It would be very important in future studies to report quality of life and comorbidities before and after any invasive treatment to be able to analyse the possible effect of different interventions on patient outcome.

Our study has some limitations. Because this was a retrospective study, we could not retrieve all data pertinent for the study. Furthermore, 24 patients out of 79 did not complete the EQ-5D questionnaire. We can only guess the reasons. Whether the missing data from the 30% of the patients represent a group with poor quality of life and high dependence on continuous support remains unresolved. On the other hand, quality of life was analysed only for those patients with data available both before and after CA. The total number of patients was rather small. Therefore, it is prudent to state that caution should be exercised in the interpretation and extrapolation of the data. It must also be emphasized that EQIndex does not directly correlate with the patient's cognitive outcome.

We conclude that the quality of life 6 months, in this highly selected group, after CA was surprisingly good in CA survivors, even those with numerous comorbidities. The best predictor for good quality of life after CA was good quality of life prior to CA. In future studies, it is prudent to include pre-CA quality of life into analyses when assessing the possible benefits of targeted temperature management and other invasive treatments, such as coronary interventions.

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