

# **Lifesaving after cardiac arrest due to drowning**

**Characteristics and outcome**

Andreas Claesson

Department of Molecular and Clinical Medicine/Cardiology  
Institute of Medicine  
Sahlgrenska Academy at the University of Gothenburg



UNIVERSITY OF GOTHENBURG

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andreas.claesson@telia.com

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*“If I have seen a little further, it is by standing on ye shoulders of giants”*

Isaac Newton, letter to Robert Hooke, 5 February 1675

*To my family*

# Lifesaving after cardiac arrest due to drowning

## Characteristics and outcome

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Department of Molecular and Clinical Medicine/Cardiology, Institute of  
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Sahlgrenska Academy at the University of Gothenburg  
Göteborg, Sweden

### ABSTRACT

#### Aims

The aim of this thesis was to describe out-of-hospital cardiac arrest (OHCA) due to drowning from the following angles. In Paper I: To describe the characteristics of OHCA due to drowning and evaluate factors of importance for survival. In Paper II: To describe lifesaving skills and CPR competence among surf lifeguards. In Paper III: To describe the characteristics of interventions performed by the Swedish fire and rescue services (SFARS) and evaluate survival with or without rescue diving units. In Paper IV: To describe the prevalence of possible confounders for death due to drowning. In Paper V: To describe changes in characteristics and survival over time and again to evaluate factors of importance for survival

#### Methods

Papers I and III-V are based on retrospective register data from the Swedish OHCA Register reported by Emergency Medical Service (EMS) clinicians between 1990-2011. In addition, in Paper III, the data have been analysed and compared with the SFARS database for rescue characteristics. In Paper IV, the data have been compared with those of the National Board of Forensic Medicine (NBFM). Paper II is a descriptive study of 40 surf lifeguards evaluating delay and CPR quality as performed on a manikin.

#### Results

Survival in OHCA due to drowning is about 10% and does not differ significantly from OHCA with a cardiac aetiology. The proportion of

witnessed cases was low. Survival appears to increase with a short EMS response time, i.e. early advanced life support.

Surf lifeguards perform CPR with sustained high quality, independent of prior physical strain.

In half of about 7,000 drowning calls, there was need for a water rescue by the fire and rescue services. Among the OHCA in which CPR was initiated, a majority were found floating on the surface. Rescue diving took place in a small percentage of all cases. Survival when using rescue divers did not differ significantly from drownings where rescue diving units were not used. No survivors were found after >15 minutes of submersion in warm water. After submersion in cold water, survival with a good neurological outcome was extended.

Among 2,166 autopsied cases of drowning, more than half were judged as accidents and about one third as intentional suicide cases. Among accidents, 14% were found to have a cardiac aetiology, while the corresponding figure among suicides was 0%.

In a 20-year follow-up of OHCA due to drowning in Sweden, both bystander CPR and early survival to hospital admission are increasing. The proportion of cases alive after one month has not changed significantly during the period.

## **Conclusions**

Survival from OHCA due to drowning is low. A reduction in the EMS response time appears to have high priority, i.e. early ALS is important. The quality of CPR among surf lifeguards appear to be high and not affected by prior physical strain. In all treated OHCA cases, the majority were found at the surface and survival when rescue diving took place did not appear to be poorer than in non-rescue diving cases.

In a minor proportion of cases, cardiac disease could be a confounder for death due to drowning. Bystander CPR in OHCA due to drowning has increased over a 20-year period and the proportion of early survivors to hospital admission is increasing. We speculate that our studies were underpowered with regard to the opportunity adequately to assess the effects of bystander CPR on survival to hospital discharge.

A uniform Swedish definition of drowning based on the recommended international terms should be implemented throughout Swedish authorities and health care, in order to enhance the quality of data and improve the potential for future research.

**Keywords:** Drowning, Cardiac arrest, CPR, Lifesaving

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# SAMMANFATTNING PÅ SVENSKA

## Frågeställning

Föreliggande avhandling avser att beskriva hjärtstopp på grund av drunkning utifrån följande aspekter: Faktorer av betydelse av prognos, prognostiska förändringar över tid, räddningstjänstens insatser, förekomst av andra bidragande faktorer till död samt havslivräddares kompetens.

## Metodik

Avhandlingen har i delarbete I samt III-V baserat sig på retrospektiva registerdata från Svenska registret för hjärtstopp utanför sjukhus under åren 1990-2011. I tillägg har data analyserats och jämförts i delarbete III med räddningstjänstens insatsdatabas för larm samt i delarbete IV med rättsmedicinalverkets databas för obducerade fall. I delarbete II genomfördes en deskriptiv studie på havslivräddare vad avser tidfördröjning vid räddning i hav samt kvalitet på Hjärt-lungräddning (HLR) såsom utförd på docka.

## Resultat

Överlevnaden vid hjärtstopp i samband med drunkning är drygt 10 % och skiljer sig inte signifikant från hjärtstopp av kardiell natur. Andelen bevittnade fall var låg. Överlevnaden var högre vid kortare ambulansresponstid. I utvärdering av havslivräddare visades det att de utför HLR med hög kvalitet oberoende av fysisk ansträngning.

I hälften av ca 7000 drunkningslarm till räddningstjänsten krävdes en räddningsinsats. I de fall då hjärt-lungräddning påbörjades av ambulanspersonal återfanns majoriteten i ytan. Andelen fall där dykinsats utfördes var låg. Prognosen bland dessa var likartad i jämförelse med övriga fall. Inga överlevare rapporterades efter > 15 minuter under ytan i varmt vatten. Vid drunkning i kallt vatten utökades tidsgränserna för överlevnad med god neurologisk funktion.

Bland 2166 obducerade fall av drunkning så var mer än hälften bedömda som olycksfall och ca en tredjedel som avsiktliga suicid. Bland olycksfallen hade 14% en kardiell etiologi, proportionen bland de avsiktliga drunkningarna var 0%.

I en 20 års uppföljning av hjärtstopp på grund av drunkning i Sverige visas att andelen fall som läggs in levande på sjukhus är i ökande, så även andelen fall som får livräddaringringripande med tidig HLR före ambulansens ankomst till platsen. Andelen fall som är vid liv efter en månad har däremot inte förändrats.

### **Slutsatser**

Idag är överlevnaden efter hjärtstopp på grund av drunkning låg. Av tänkbara åtgärder för att förbättra överlevnaden förefaller förkortning av ambulansens responstid och tidigt insättande av avancerad hjärt-lungräddning (A-HLR) vara viktigt. Kvaliteten på HLR bland havslivräddare förefaller vara hög och ej påverkad av den fysiska ansträngningen. Bland alla rapporterade och behandlade hjärtstopp på grund av drunkning så återfanns majoriteten i ytan. Överlevnaden när räddningsdykare inom räddningstjänsten användes var inte sämre än i fall utan räddningsdykning.

I en mindre andel av dödsfall på grund av drunkning kan kardiella faktorer ha bidragit. Andelen som får tidig HLR har ökat under en 20-års period och andelen fall som läggs in levande på sjukhus förefaller vara i ökande. Vi spekulerar i att vårt studiematerial är för litet för att kunna dokumentera effekten av tidig HLR på överlevnaden till 30 dagar efter inträffat hjärtstopp på grund av drunkning.

En Svensk drunkningsdefinition baserad på den internationellt rekommenderade terminologin bör implementeras hos Svenska myndigheter samt inom sjukvården, detta för att öka kvaliteten på data och för att förbättra möjligheterna till framtida forskning.

# LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

- I. Claesson A, Svensson L, Silfverstolpe J, Herlitz J. Characteristics and outcome among patients suffering out-of-hospital cardiac arrest due to drowning. Resuscitation. 2008 Mar;76(3):381-7
- II. Claesson A, Karlsson T, Thorén AB, Herlitz J. Delay and performance of cardiopulmonary resuscitation in surf lifeguards after simulated cardiac arrest due to drowning. Am J Emerg Med. 2011 Nov;29(9):1044-50.
- III. Claesson A, Lindqvist J, Ortenwall P, Herlitz J. Characteristics of lifesaving from drowning as reported by the Swedish Fire and Rescue Services 1996-2010. Resuscitation. 2012 Sep;83(9):1072-7
- IV. Claesson A, Druid H, Lindqvist J, Herlitz J. Cardiac disease and probable intent after drowning. Am J Emerg Med. 2013 Jul;31(7):1073-7. doi: 10.1016/j.ajem.2013.04.004. Epub 2013 May 20.
- V. Claesson A, Lindqvist J, Herlitz J. Cardiac arrest due to drowning: Changes over time and factors of importance for survival. Submitted

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## ABBREVIATIONS

AED	Automated external defibrillator
AHA	American Heart Association
ALS	Advanced life support
AMI	Acute myocardial infarction
ARDS	Adult respiratory distress syndrome
BLS	Basic life support
CA	Cardiac arrest
CPA	Cardiopulmonary arrest
CPAP	Continuous positive airway pressure
CPC	Cerebral performance category
CPR	Cardiopulmonary resuscitation
ECG	Electrocardiography
ED	Emergency department
EMS	Emergency medical services
EMT	Emergency medical technician
ERC	European Resuscitation Council
ETI	Endotracheal intubation
FLISA	Federation of Leaders In Swedish Ambulance services
HIC	High-income countries
ICD	International classification of diseases

ICU	Intensive care unit
ILCOR	International Liaison Committee on Resuscitation
ILS	International Lifesaving Society
IQR	Interquartile range
IWR	In-water resuscitation
LMA	Laryngeal mask airway
LMIC	Low- and middle-income countries
LQTS	Long QT syndrome
NBFM	National Board of Forensic Medicine
NBHW	National Board of Health and Welfare
Non-IWR	Non-in-water resuscitation
NSE	Neuron-specific enolase
OHCA	Out-of-hospital cardiac arrest
PCP	Phencyclidine
PEA	Pulseless electric activity
RN	Registered nurse
ROSC	Return of spontaneous circulation
SCUBA	Self-contained underwater breathing apparatus
SD	Standard deviation
SFARS	Swedish Fire and Rescue Services
SIDS	Sudden infant death syndrome

SLS	Swedish Lifesaving Society
SLSC	Surf lifesaving club
SCCA	Swedish Civil Contingencies Agency (MSB)
SRC	Swedish Resuscitation Council
VF/VT	Ventricular fibrillation/ventricular tachycardia
WHO	World Health Organisation

## BRIEF DEFINITIONS

<b>CA</b>	Cardiac arrest is the loss of spontaneous circulation, victim found unconscious with no or abnormal/agonal breathing. Arrhythmias are VF/VT, PEA or asystole.
<b>DALYs</b>	Disability Adjusted Life Years is the sum of years of potential life lost due to premature mortality or years of productive life lost due to disability.
<b>EMS Clinicians</b>	In the 1990's mainly nursing assistants with 20 weeks of prehospital training. In the 2000's mainly registered nurses (RN) with or without an additional year of prehospital education in university.
<b>Immersion</b>	Victim immersed in liquid with his or her airways above the surface of the liquid, where the liquid is usually water.
<b>OHCA</b>	Out-of-hospital cardiac arrest in which CPR and/or defibrillation was given.
<b>ROSC</b>	Return of spontaneous circulation is sustained cardiac activity with a palpable pulse any time during CPR for an unspecified amount of time.
<b>Submersion</b>	Victim submerged in liquid with his or her airways beneath the surface of the liquid, where the liquid is usually water.

## RATIONALE FOR THIS THESIS

Basic curiosity about the human body, together with coincidences in life, brought me from general fire and rescue schooling towards more specific surf lifesaving training in Tylösand in southern Sweden in 1996. After additional lifesaver courses in Australia and South Africa, several victims from drowning were encountered and the need for immediate action was understood.

When I first started working as an emergency medical technician and subsequently as a registered nurse and paramedic in the ambulance services, I realised the impact and importance of early intervention and a widespread knowledge of CPR in the community.

Further, I recognised the need for an understanding of the characteristics and the mechanisms that might influence survival from out-of-hospital cardiac arrest due to drowning. A basic knowledge of this cohort of patients could give us vital information for both preventive measures and possible interventions in the pre-hospital setting.

As the years have passed, the extent of available knowledge and research gaps in the field has evolved and become all too clear. There is still work to be done, but, if only one additional life could be saved by a fellow human being based on our findings, this thesis is worthwhile.

# 1 INTRODUCTION

## 1.1 Epidemiology

The World Health Organisation, WHO, estimates that drowning is the third leading cause of unintentional deaths after road traffic accidents and falls worldwide. Drownings account for about 7% of all deaths related to injury globally each year. In the early 2000s, an estimated 388,000-450,000 drownings occurred each year in the world, although this figure most probably underestimates the problem. Low- and middle-income countries (LMIC) account for about 96% of all accidental drownings in the world. China and India alone account for 43% of all reported accidental drownings and 41% of all reported disability-adjusted life-years (DALYs) lost each year due to drowning. An estimated further 1.3 million (DALYs) are lost globally each year due to premature death and neurological disabilities due to drowning. (1, 2)

Drowning rates in Africa are about eight times as high as they are in the USA and in Australia. Drowning is a major paediatric problem, in China, drowning is the leading cause of accidental death in children aged 1-14 years. In the USA, drowning is the second leading accidental cause of death for children of the same age. In Bangladesh, drowning accounts for as many as 20% of all deaths in 1- to 4-year-old children. (2)

Male gender appears to be over-represented in drowning statistics, with an almost fivefold increase in the risk of drowning as compared to females.(3, 4)

Data from Bangladesh report drowning rates of 215/100,000 inhabitants and year and, in 1- to 2-year-old boys, rates of 546/100,000 inhabitants and year. Many childhood drownings occur in the morning in nearby ponds, while a relative, usually the mother, is occupied by household activities. Knowledge of the appropriate rescue measures is still frequently low when it comes to treatment. Spinning the child overhead was more frequent than performing CPR, as shown in a recent study from rural areas of Bangladesh. (5)

These data can be compared with data from a high-income country (HIC) such as the USA showing drowning rates in 1-to 4-year-olds of 3/100,000 inhabitants and year. (6)

In Sweden, drowning in children aged 0-17 years has declined in recent years to approximately 10 cases a year, about 0.6 drownings/100,000 inhabitants

and year. Drowning is, however, still the leading cause of death in Sweden in children aged 1-6 years. About one third of all drownings occur in bathing areas when supervision has failed and pre-school children often drown in shallow ponds close to their home. (7)

Not all drownings are unintentional accidents. Emergency Medical Services (EMS), fire and rescue services and police authorities respond to drowning calls on a regular basis throughout Sweden, regardless of initial victim intent. In the initial phase, it is most often not known whether the drowning is accidental or intentional.

In 2010, data from the Swedish National Board of Health and Welfare and its register of causes of death revealed that a total of  $n = 135$  drownings were reported. Of these, 30% ( $n=41$ ) were due to intentional drowning (ICD-X71). A further 10% ( $n=14$ ) were categorised as unclear cases (ICD-Y21). The remaining 60% ( $n=80$ ) were clearly accidental cases. (8) Paper IV in this thesis deals with the characteristics of intentional drowning cases, as reported by the National Board of Forensic Medicine.

### 1.1.1 Global data acquisition

Drowning data are frequently uncertain, as the statistics may lack information and the existing quality of the data in LMIC is often poor. Data in HIC is as well often poor and not coordinated between authorities on a national level. The burden of drowning may also be higher because some cases of drowning are coded incorrectly in the *International Classification of Disease*, ICD, system. Usually, ICD10 codes W65-W74 are used for international comparisons of drowning, while V90, V92, boating-related drowning, are classified as transportation-related death. (9) Floods and tsunamis are other types of accident that are not included in the official statistics. (3)

Sometimes, drowning cases can be categorised as something other than drowning and are therefore not included in general drowning statistics. Smith et al. found 18% “new” drowning cases when analysing mortality files in the USA between 1977-1992. Of these, the majority (65%) were categorised as motor vehicle accidents. (10)

The International Lifesaving Society (ILS) drowning prevention commission reported data from a survey in 2011. Of just over 100 affiliated members, there were a total of 47 responding countries and 25 of these had drowning data to present. The responding HIC which collected data did this at national level in 93%. Some countries (7%) only collected data at provincial level. For LMIC, 67% of countries had national data available. Data on resuscitation

was only available in about half of all cases reported in the survey. In 2004, the reporting of overall death registration data (mortality and causes of death) to the WHO took place in 115 countries. The quality of the data was good in about two thirds of reporting countries. (11)

### **1.1.2 Prognosis**

Survival and neurologically good outcome after cardiac arrest due to drowning is difficult to predict accurately in the pre-hospital setting, as well as in the early phases of intensive care. Although there are miracle cases (12-15) i.e. survival with good neurological outcome when it was not expected, many drowning victims end up with hypoxia-induced neurological damage impairing quality of life even after short submersion times. (16)

A short submersion time, early CPR and the presence of spontaneous breathing appear to be associated with a good prognosis. Children with a good motor response to pain stimuli after OHCA have a better outcome than those without this kind of response. (16, 17)

#### **Submersion time**

Quan et al. however, found that some predictors of outcome were already accessible in the pre-hospital setting. Factors predicting a poor outcome were submersion times longer than 10 minutes and resuscitation prolonged for more than 25 minutes. Predictors of a good outcome were short submersion times, sinus rhythm in conjunction with the return of spontaneous circulation (ROSC), pupils reacting to light and response to pain stimuli. (18)

In a study by Suominen et al. the only independent predictor of a good outcome was short submersion times and neurologically intact survivors had a median submersion time of only five minutes. (19) Szpilman et al. concluded in a recent review that the increase in death or a neurologically poor outcome was 10% in submersions lasting 0-5 minutes, 56% in submersions of 6-10 minutes, 88% in submersions of 11-25 minutes and about 100% in submersions of more than 25 minutes. (3)

#### **Water temperature**

The data on the effect of water temperature as a prognostic factor for survival are inconsistent. (20, 21) Case reports, however, indicate that drowning in icy waters could be neuroprotective. (12-15, 22)

Tipton et al. suggested a decision-making guide based on water temperature and submersion time as a prognostic factor for calculating the chance of survivable rescue. In waters with a temperature of < 6 degrees, search and

rescue should persist for up to 90 minutes of submersion and CPR should be initiated within this time period. In water temperatures of > 6 degrees, search and rescue followed by CPR should persist for 30 minutes. After these time intervals, survival appears to be extremely unlikely and the rescue of the drowning victim should instead be followed by body retrieval. (15) Further studies on the effect of water temperature on survival should however be done to accurately describe the relationship.

## 1.2 Definitions and terminology

Papa et al. performed a systematic review and found, in preparation for the World Congress on drowning in the Netherlands in 2002, a total of 33 definitions of drowning and 20 of the outcome of drowning. (23)

Early definitions of drowning, such as “near-drowning”, implied that there was a certain, successful rescue and that the victim would survive the event. This was, however, not always the case, as several victims who were revived and even conscious died days after the event, which Modell recognised in 1971. (24) Modell changed the terminology in 1981 and introduced terms such as drowning with and without aspiration and “drowned” versus “near-drowned”. (25)

### 1.2.1 ILCOR drowning definition

A new definition of drowning was needed, because the existing definitions and terms were confusing in daily practice. A new drowning definition was prepared and proposed by the International Liaison Committee On Resuscitation (ILCOR) as an ILCOR advisory statement during the World Congress on Drowning held in Amsterdam on 26-28 June 2002.

*”Drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium. Implicit in this definition is that a liquid/air interface is present at the entrance of the victim’s airway, preventing the victim from breathing air. The victim may live or die after this process, but whatever the outcome, he or she has been involved in a drowning incident.”*

Outcome should be classified as death, morbidity and no morbidity. (26, 27)

This definition has become standard in the scientific community over the years, although a Swedish translated version is yet to be presented.

## 1.2.2 Drowning terminology

Several terms have previously been used to describe the drowning event. Several of them are misleading and visualise changing aspects. The ILCOR no longer recommends that the terms listed below should be used. The terms are, however, presented in this thesis in order to understand the problems associated with using these terms.

### **Dry-drowning versus wet-drowning**

In accordance with the ILCOR drowning definition, all drownings occur in liquid, mostly water, and are thereby wet. Dry- versus wet-drowning used to refer to autopsy findings. Victims who aspirated liquid into the lungs could have an increase in lung weight and visible water in the lungs and were therefore classified as wet-drownings. Those that had dry lungs during autopsy were classified as dry-drownings. It is not obvious for a rescuer to determine at the accident scene whether liquid has been aspirated or even the amount of inhaled water. Large amounts of water in the lungs can also enter the circulatory system via osmosis, showing little or no water in the lungs during CPR and/or autopsy. A drowning could have occurred without obvious signs at the accident site. *The ILCOR no longer recommends that this term should be used. (26)*

### **Drowned versus near-drowned**

The term “near-drowned” has historically implied survival, while “drowned” has implied death. Several victims of near-drowning die from respiratory complications such as Adult Respiratory Distress Syndrome (ARDS), at Intensive Care Units (ICU), days to weeks after the drowning. This makes the terms uncertain in clinical use. The translation of the term to Swedish (“nära-drunkning” or “drunkningstillbud”) has the same meaning as the English, near-drowned. *The ILCOR no longer recommends that this term should be used. (26)*

### **Active versus passive drowning**

These terms seek to describe a type of movement during a drowning.

“Passive, silent drowning” has historically been used to describe a victim drowning without anyone witnessing the event. Active drowning represented someone screaming and splashing.

A better and more accurate term in accordance with the modern Utstein style for the uniform reporting of data from drowning is “witnessed” or “unwitnessed”. *The ILCOR no longer recommends that this term should be used. (26)*

### **Secondary drowning**

The term has described two different events in the terminology associated with drowning cases. Firstly, it has previously been used when a person suffers from epilepsy, acute myocardial infarction, (AMI), or other medical or traumatic events and secondarily drowns as a result of impaired swimming ability. The term has also been used in the ICU to describe death after ARDS or other respiratory or circulatory complications. This is confusing, as the victims do not suffer a second drowning event. *The ILCOR no longer recommends that this term should be used.* (26)

## **1.3 Pathophysiology**

Hypoxaemia is the primary and most important pathophysiological complication in the drowning victim and the alleviation of hypoxaemia is therefore essential for survival. (28)

### **1.3.1 Breathholding and ventilation**

In a forensic study, Lunetta et al. concluded that, for drowning to have taken place, the victim must have aspirated water or show signs of lung injury such as atelectasis in order to define the event as a drowning. (29) This is in line with the ILCOR definition of drowning. (27)

In cases in which the pre-existing cause of drowning is fatigue from any cause, the victim will at some point experience problems keeping the airways clear of fluid, most frequently water. Water entering the mouth in a conscious victim is initially swallowed or spat out. When submersion of the airways occurs, the victim will voluntarily hold his or her breath for as long as possible. How long this period lasts will most probably depend on the water temperature, the degree of stress, as well as habituation in the individual, probably less than 60 seconds. (30, 31)

Hypoxaemia is the most important factor in drowning cases. After submersion and initial breathholding, involuntary breathing will take place. Due to the inspiratory drive caused by carbon dioxide, pCO<sub>2</sub>, the victim will immediately breathe water, which will enter the airways causing coughing and/or laryngospasm. The exact incidence of victims suffering from laryngospasm at this stage still appears scientifically unclear and large volumes of water could be aspirated at an early stage. (3)

Layon and Modell argue that the aspiration of water may not occur for up to 1.5-2 minutes in some individuals due to laryngospasm. In these cases, the

immediate restoration of ventilation and circulation could reverse the hypoxaemia and prevent cardiac arrest and subsequent pathophysiological complications. (28)

The instillation of large amounts of fluid in canine models of anaesthetised dogs show struggling, body movements and the immediate respiration of large tidal volumes for more than one minute. Normal blood pressure remained for two minutes and, after this stage, agonal breathing as well as blood pressure were recordable but decreased and first reached zero after four minutes. (32)

As central hypoxia increases due to the reduction in oxygen diffusion in the alveoli, the victim becomes unconscious and the eventual laryngospasm quickly subsides. The victim may then aspirate large amounts of fluid into the lungs, which further decreases the diffusion of O<sub>2</sub> and also causes a washout of surfactant. The washout of surfactant increases the hypoxia, as the alveoli lose their surface tension. (28, 33)

### **1.3.2 Circulation**

The hypoxic event will probably induce a tachycardia, followed by bradycardia and, in canine models, an increase in circulating catecholamines. (34) If the drowning process is not interrupted, pulseless electrical activity, PEA, usually occurs, followed by asystole. Cardiac arrest will occur within seconds to a few minutes after the cessation of breathholding during submersion. (32) Victims are most often found in a non-shockable rhythm resulting from a primary respiratory arrest. Drownings resulting from a primary circulatory arrest with a cardiac aetiology could also occur due to the fact that the victim happened to be in water. (35)

If the drowning occurs secondarily to an arrhythmic event, the initial arrhythmia as recorded on an electrocardiogram (ECG) can be of ventricular origin, ventricular fibrillation or ventricular tachycardia, VF/VT. Cardiac channel mutations, such as swimming-triggered long QT syndrome 1, LQT1, are an example of a probably relatively rare pre-existing arrhythmia that might cause drowning. (36-39)

### **1.3.3 Neurology and further management**

Cold exposure with profound hypothermia has been shown to induce bradycardia. (40) General hypothermia is reported to be neuroprotective in cases of drowning by reducing oxygen needs in the tissues and, most importantly, the brain. When aspirating cold water, cooling of the blood will

take place as long as cardiac activity is present, selective brain cooling. If tissues in the brain are hypothermic, submersion times, still resulting in survival with close to full recovery, could be extended. (15, 41) Canine models have shown that core body temperature can be reduced by seven to eight degrees in two minutes due to ventilation of cold water while there is still heart activity and circulation of the blood. (32, 34)

Early high levels of neuron-specific enzymes such as neuron-specific enolase (NSE) and S100B have been shown to be present in CA due to drowning, showing signs of cerebral damage. (42, 43) Levels of NSE and S100B are low in cases of hypothermic cardiac arrest, indicating some protection from cerebral damage. (14)

Drowning victims arriving at the emergency department, ED, in a conscious or arousable state appear to have a good prognosis for both survival and neurological outcome. (28) Conn et al. and Modell et al. found that 90%-100% of these victims survived with an acceptable neurological outcome without sequelae corresponding to a cerebral performance category (CPC) score of 1-2. (44, 45) In a review by Souminen et al. six studies of neurological follow-up were identified. In all, 4-27% of victims suffering from OHCA due to drowning ended up in a vegetative state corresponding to CPC 3-5. (16)

Cognitive impairment appears to be common in survivors of cardiac arrest. About half suffer from memory loss, attention disorders and disturbances in executive functioning such as problem solving, multitasking and reasoning. Memory loss appears to be the most common disorder post-drowning. (46)

Drowning victims and others with acute neurological damage should receive intensive care with the goal of achieving normal values of partial pressure of oxygen and carbon dioxide (pO<sub>2</sub> and pCO<sub>2</sub>) and blood glucose levels. Further, therapeutic hypothermia, induced at 32-34 degrees Celsius for 24 hours, could be neuroprotective and prevent further brain damage to some degree. (47, 48)

However, in comatose patients, about 50% recover to survival with a good functional state (CPC score 1-2), whereas 10-20% survive but remain in a vegetative state (CPC 3-5). The remaining 30-40% die in the intensive care unit, ICU. (28, 44, 45)

A long-term follow-up of neurological status is recommended in order to reveal persistent sequelae that are perhaps not obvious at hospital discharge. (16)

Following the restoration of ventilation and circulation, the arterial oxygenation is still affected by even small quantities of inhaled fluids, 1-2 ml/kg. (28) Fluid in the alveoli causes local damage and prevents the perfusion of blood gases over the membrane. It also obstructs the bronchioli, causing atelectasis. Hypertonic seawater has been shown to withdraw fluid from the bloodstream, increasing lung fluids and causing hypovolemia. Hypotonic fresh water is absorbed to the blood, sometimes showing no fluid in the lungs but, on the other hand, general hypercarbia due to the hemolysis of red blood cells and acidosis due to the increasing hypoxia. Water in the lungs causes the washout of surfactant with subsequent alveoli collapse. The clinical picture is that of a victim in severe hypoxemia with sometimes bloodstained lung oedema and electrolyte shift with hypercarbia. Airway and ventilation management is the main concern. (28)

## **1.4 History of treatment**

Through most of the documented time of life for humans on earth, people appear to have shown a sense of caring for one another. People have tried to assist in cases of sudden cessation of life, performing mainly pulmonary resuscitative measures. Cardiopulmonary resuscitation as we know it today is the result of three different techniques: ventilation, cardiac compressions and electrical defibrillation. (49)

Throughout history, there have been three main movements in pulmonary resuscitation techniques. The expired air method involving mouth-to-mouth/nose ventilation which has come and gone, secondly, the bellows methods using pumps, fireplace bellows or similar equipment and, lastly, the postural, push and pull techniques, Hall, Silvester, Schafer, Nielsen and others. (50)

### **1.4.1 Early beliefs**

Death was thought of as a form of deep sleep and resuscitation could therefore be prolonged for many hours. The techniques that were applied could consist of obscure methods and painful stimuli such as beating the victim in the face, burning him or her with glowing coal or sticking needles into the body. (4)

As body temperature decreases after death, methods of re-warming were recommended by the Royal Humane Society in the United Kingdom in the 1800s, for example. Bottles of warm water or hot bricks were placed under the armpits, on the stomach or under the feet of the victim. Warming the victim over a fire or throwing hot mud, animal faeces or hot ashes onto the body were other means of reviving a drowning victim. In China, victims could be placed in hot oil baths for the same reason. Victims could also be tied hanging over an ox with a rescuer holding the body in place, while the ox ran and some kind of stimulus was applied to the chest of the victim, perhaps an early form of mechanical chest compressions. Screaming, rubbing the body with sea salt or whipping the body with thorny bushes were other techniques that were frequently used. In Russia, victims could be buried in sand up to their necks, after which cold water was splashed on their faces to wake them from the dead. (4, 50)

The first findings of resuscitative efforts are primarily found in religious writings, from the Bible in the book of Genesis 2:7 and in the Book of Kings 4:34-35, where Elijah may have performed artificial respiration. From the Book of Exodus, written between 1900-1100 BC, Puah, who was a midwife, is described as reviving newborn babies with her own breath. (4)

In 177, Galen was said to have used expired air ventilation using bellows to inflate the lungs of dead animals. (49) An early description of resuscitation from drowning is when, in ancient times, the Egyptian Pharaoh, Rameses II, threw the King of Aleppo in today's Syria into the River Orontes, after which his soldiers hung him by his feet perhaps to drain water from the lungs. (4)

## 1.4.2 Ventilation techniques

The documentation of rescue techniques were missing for several centuries and it was not until the 14th century that descriptions started to appear in the literature again. Andreas Vesalius (1514-1564) worked as a professor in Italy and showed, by placing a tube down the trachea of animals, that, for the heart and circulation to function, ventilation is necessary. His findings were published in his book *De Fabrica Humana Corporis*. (51)

The Paris Academy of Sciences recommended mouth-to-mouth ventilation in drowning victims back in 1740. An early description of successful mouth-to-mouth ventilation came from Scotland and Tossach in 1744, where, after ventilating a collapsed miner, he felt several heartbeats. (52) It became more and more obvious to the scientific community that death was not irreversible. (4, 50)

However, although reports of successful rescues in newborns and drowned persons after performing mouth-to-mouth ventilation appeared, there were doubts about executing the technique. Firstly, the aesthetic aspect of physical contact repelled many people, as well as the thought of the risk of contracting contagious diseases by physical contact with the victim's mouth. A bag for ventilation was developed as a way of safe ventilation (Chaussier). In 1796, Herholdt and Rafn showed that expired air was harmless and not toxic to the victim. (50)

In 1783, Goodwyn described the physiology of the tongue obstructing the airway. The scientific community also reasoned about the use of endotracheal intubation in unconscious victims. (50) At about the same time, Kite and Squires experimented with an apparatus similar to a modern defibrillator. Kite developed the "Bottle of Leiden", a capacitor with copper poles and wooden handles. (53)

Squires is said to have resuscitated a three-year-old child, Sophia Greenhill, at the Middlesex Hospital in 1775 using a similar device. In Denmark, a veterinarian called Abildgaard performed similar experiments on horses and chickens using electrical currents. Evidence of the actual effect of these devices was, however, uncertain. (4, 49)

Among midwives, it appears to have been general practice and common knowledge for centuries to ventilate asphyxic newborns. In 1802, Newby published data on this, with 500 successful rescues of newborns. (4, 50)

American Indians believed that tobacco smoke held the key to and the spirit of life, as a result of which they blew smoke into the rectum of the recently dead as a way of reviving the body. These beliefs were inherited in Europe and, as a result, the Dutch fumigator was invented. The device burned tobacco in a chamber and, through a pipe, smoke was blown into the anus of the recently drowned. Brodie, however, showed the harmful effects of nicotine in canine models in 1811. In spite of this, the technique remained in use until 1860. (4, 50)

### 1.4.3 Postural techniques

After these somewhat remarkable developments during the 15th-18th centuries in the field of expired air ventilation, Leroy-d'Etiolles, a French scientist, demonstrated in a laboratory that ventilations could be lethal. As a result of excessive ventilation with high tidal volumes, animals that were alive died of pneumothorax and emphysema. D'Etiolles instead described what he regarded as more secure ways of inflating the lungs by compressions

of the chest and abdomen. Shortly after this, the Royal Humane Society recommended that mouth-to-mouth ventilation should be abandoned based on the data published by Leroy-d'Etiolles in 1829. (4, 50)

Instead of expired air ventilation and mouth to mouth, which did not re-enter guidelines until about 150 years later, postural techniques evolved in the early 19th century. The best known of the hundreds of techniques presented were Hall 1855, Silvester 1898, Schafer 1903 and Nielsen 1932. The idea behind them was to alter postures of the body and arms or compression of the shoulders and/or back so that air was squeezed out or sucked into the lungs. In a laboratory environment with intubated victims, tidal volumes of 70 ml to 1,700 ml could be achieved through these techniques. However, in a pre-hospital setting, obstruction by the tongue in the upper airways erased the positive effects of these postural techniques. However, Nielsen's technique remained in use until 1960. (4, 50, 54)

Boehm experimented with external cardiac massage and documented blood pressures in cats during compressions of the thorax in 1878. (55)

Koenig and Maass were reported to have resuscitated several cases of cardiac arrest during chloroform anaesthesia, in the 1880s. These are the earliest documented cases of modern cardiac compressions. (49, 56)

#### **1.4.4 CPR and defibrillation**

The development of home electricity was a matter of concern for the major electrical companies in the 1920s, as many of their linemen were electrocuted and died after getting electrical currents through the body. They funded research which eventually led to the first successful internal (open chest) defibrillation in man by Claude Beck in 1947 and external (closed chest) defibrillation with survival in man, published by Paul Zoll in 1956. (57, 58)

Kouwenhoven, Jude and Knickerbocker then combined ventilation, cardiac massage and defibrillation and published the first study of survival using modern CPR in 1960. By this time, postural techniques were finally on the way to being abandoned. (59)

The International Liaison Committee on Resuscitation, (ILCOR), was set up in 1992 with the aim of gathering together continental resuscitation organisations. Guidelines, albeit not totally uniform, were presented in 1992 and 1998 by the European Resuscitation Council, ERC. (60, 61)

The European Resuscitation Council is a member of the ILCOR which publishes treatment recommendations based on consensus at the ILCOR. The ILCOR has published guidelines in co-operation with the American Heart Association (AHA) on three occasions, in 2000, 2005 and October 2010. (62-64)

### 1.4.5 ERC guidelines 2010

The latest European Resuscitation Council (ERC) guidelines for CPR and treatment recommendations were published on 18 October 2010 and they focus on high-quality, uninterrupted CPR with a 30:2 ratio and early defibrillation. The recommendations are well described in the chain of survival. (65)



Figure 1. Chain of survival, ERC guidelines 2010

### 1.4.6 Aquatic rescue

When it comes to cardiac arrest due to drowning, the ERC addresses the importance of personal safety in aquatic rescue situations, in order to prevent rescuers themselves being victims, which can sometimes be the case. (66)

Many rescues are performed by bystanders and there is evidence that bystanders are often willing to perform rescues even in dangerous aquatic environments, such as multiple victims, cold water, deep water or rescuers being young. It is, however, important to address the importance of personal safety by staying on dry land if possible. (67)

Means of rescuing the drowning victim can include talking to the victim, reaching out to him/her with a stick, clothing or throwing a rescue line or lifebuoy from land. If the rescuer feels confident about performing a water rescue, a buoyant aid is advised. The techniques that are applied should all aim to remove the drowning victim from the water as quickly and safely as possible. (64) Paper II in this thesis deals with surf lifeguards and their performance of CPR and delay during simulated rescue.

### **1.4.7 In-water resuscitation**

In a drowning process, the most important thing is to disrupt the escalating hypoxia and ensure adequate ventilation, preferably already in the water. Rescue breathing can be initiated in water and could be an important intervention in increasing survival. In-Water Resuscitation (IWR) could prevent a cardiac arrest by early re-oxygenation. (68)

The ERC recommends IWR in deep water only if rescuers are trained to perform it and using adequate equipment such as a life buoy, an aquatic rescue tube or a rescue board or the equivalent, see figure 2. If the victim is unconscious with abnormal breathing, 10-15 ventilations should be administered as quickly as possible during the course of one minute, either by mouth-to-mouth ventilation or, alternatively, mouth-to-nose ventilation.

With a short distance to shore (less than five minutes away), ventilations should be performed continuously while towing. However, if the distance is greater (more than five minutes away), ventilations should be administered for another minute, whereafter the rescuer should focus on bringing the victim to shore without further ventilations en route. (68, 69)

In shallow water, IWR could be performed by many bystanders by opening the airway and giving five rescue breaths mouth to mouth. If pinching the nose is difficult, the rescuer could instead give mouth-to-nose ventilation or put a knee in the back of the victim for support, see figure 3. The victim should be brought ashore as quickly as possible after these first five rescue breaths. The victim should be placed on solid land away from incoming waves, alongside but above the waterline and with the head and trunk at the same level. (69) See appendix for the CPR in drowning algorithm.



*Figure 2. Example of positioning in deep water using a rescue-board. Rescuer opens the airway of the victim and checks for breathing prior to administering in-water resuscitation (early ventilations).*



*Figure 3. Example of positioning in shallow water using a knee for support. Rescuer opens the airway of the victim and checks for breathing prior to administering in-water resuscitation (early ventilations).*

### **1.4.8 Basic life support**

Calling for help at an early stage is advised, preferably before entering the water. Administering chest compressions in water is ineffective. The compressions and ventilations that are performed should be of high quality. If not administered earlier, five rescue breaths should be given as quickly as possible and a great deal of water can come out during this treatment. Adequate ventilation is probably more difficult to perform in drowning cases, as water in the airways will interfere with gas exchange in the lungs. CPR should be administered using a 30:2 ratio, 30 compressions and two ventilations. Ventilations are important in drowning cases, as most drowning victims suffer CA due to primary hypoxia. Compressions only are probably less effective in the drowning cohort of CA patients and are not recommended. An AED should be used, if available, and it is important to dry the chest before applying ECG electrodes, as they might not stick if the chest is wet. (69)

The aspiration of water is implicit in the definition of drowning. The regurgitation of stomach contents can further complicate the treatment. The patient should be rolled onto his/her side and the airways should be cleared manually with the fingers if regurgitation makes ventilation impossible. In drownings, high insufflation pressures are often needed due to the reduced compliance of the lung tissue and because of liquid in the airways. Ventilations using the 30:2 ratio should be continued until the arrival of EMS clinicians. (69)

### **1.4.9 Advanced life support**

For the normally breathing victim suffering from a drowning, oxygen should be administered at a high flow, 15 litres/minute through a reservoir mask if the saturation is less than 94%. A continuous positive airway pressure mask (CPAP) can be considered as a way of increasing oxygenation if the patient fails to respond to the reservoir mask. In OHCA, early intubation via tracheal cuffed tubes is recommended prior to laryngeal mask devices, due to the risk of leakage when applying high inflation pressures to the airways using a laryngeal mask. Cricoid pressure can reduce the risk of aspiration during intubation and should be applied. It is important to use a suction device to clear the upper airways and make the larynx visible, as well as to expel water and oedematous fluid from the airways. When the tube is in place, the concentration of oxygen should be titrated to reach a target value of 94-98% saturation. Saturation levels can be difficult to evaluate, as the patient often has cold extremities with low circulation. (70)

The standardised national advanced life support (ALS) algorithm should be followed and CPR should be initiated as early as possible. Most drowning victims suffer from a primary respiratory arrest causing the cessation of circulation as hypoxia increases in the body. It is also important to remember that some drowning victims may suffer a primary circulatory arrest in the water. (69)

The initial evaluation of whether or not the breathing pattern is normal is difficult, as the breathing patterns of a gasping patient are not well known to the general public. Many drowning victims are hypothermic and it can be difficult to tell how deep the hypothermia is in the field. The administration of drugs should be withheld and no more than three shocks should be administered if the patient is believed to have a core body temperature of below 30 degrees Celsius. (69)

As many drowning victims are hypothermic, it is not feasible to stop resuscitation in the field unless the body shows clear signs of death such as frozen ice or snow in the airways, stiffness of the joints and jaw or decomposing tissues. Prolonged survival has been shown in extreme cases involving mainly children submerged in icy waters. (12, 13, 15, 71)

### **1.4.10 Post-resuscitation care**

There is little evidence relating to the preferred post-resuscitation care of drowning victims. However, since many suffer from Adult Respiratory Distress Syndrome (ARDS) and pneumonia, action should be taken to secure adequate ventilation. Many drowning victims are hypothermic and best practice is to re-warm them until spontaneous circulation occurs and keep the core body temperature at 32-34 degrees Celsius for 24 hours as is done for primary circulatory CAs. Patients suffering from deep hypothermia should be transported by the EMS services to hospitals with the ability to provide external circulation via a heart-lung machine. Hyperthermia should be avoided after drowning. A long QT syndrome (LQT1) found in the inquiries during the rehabilitation phase should provoke further genetic screening of family members. Such screening might prevent more drownings due to the same aetiology. (39, 64)

## **1.5 Prevention**

The Swedish Lifesaving Society (SLS) has probably played an important role during the last century in various aspects of prevention in the community at national level and in educating both swimming instructors and lifeguards.

The SLS draws important attention to preventive measures, provides the infrastructure surrounding aquatic environments and most probably plays a vital part in reducing cardiac arrest from drowning in the population.

### **1.5.1 Personal recommendations**

The following recommendations might prevent drowning to some extent. (3, 72, 73)

- Learn to swim and practise survival skills in the water regularly.
- Never swim alone and if possible swim in areas patrolled by lifeguards.
- Do not overestimate your own swimming capability.
- Evaluate water conditions before entry and enter unfamiliar water feet first.
- Do not enter the water after drinking alcohol.
- Use a lifejacket when appropriate in aquatic environments.
- Know how to spot a rip current and how to react if caught in one.
- Follow instructions given via safety signs and flags.

### **1.5.2 Prevention and safety for others**

Preventive strategies in order to keep other bathers safe from drowning; the following recommendations might prevent drowning to some extent.

- Encourage others to learn basic lifesaving skills and to improve their swimming ability.
- Encourage others to use life jackets and instruct them in their use in aquatic environments.
- Provide constant vigilance and supervision of children in water as well as near water.
- Put up fences around ponds and pools, install self-latching gates.
- Put up warning signs for shallow water in pools.
- Practise safe rescue techniques without entering the water yourself.
- Learn how to administer first aid and how to perform CPR. (3, 72, 74)

### 1.5.3 Swimming ability

Swimming ability in children and adults should be encouraged and has been shown to increase after swimming lessons. However, the relationship between swimming ability and reduced risk of drowning is yet to be evaluated. (75, 76)

Some data indicate that swimming ability might increase the risk of drowning in skilled swimmers, as they have increased exposure to aquatic environments and might be more likely to swim alone and in unguarded areas. It is obvious that a skilled swimmer as compared with a non-swimmer would better assure survival if the circumstances were identical. However, there are many confounders in a practical comparison. Exposure might differ between the groups and water conditions and maturity at different ages could therefore alter the relationship between drowning risk and swimming ability, making interpretations difficult. (4)

Greater swimming ability should be encouraged in children and adults, but it should also be accompanied by mature behaviour and company when in and near water. (7)

Parents whose children had been in a drowning incident showed more vigilance than parents whose children had not. The latter often overestimated their children's ability to swim. (77) Parents also often believe that the best way of preventing drowning in toddlers is the provision of swimming lessons rather than supervision. (78)

For self-rescue swimming, it has been shown that it is possible to swim a distance of 800-1,500 metres, for a period of about 47 minutes in a water temperature of 10-14 degrees Celsius. Subjects often overestimate the distance they need to swim in an emergency. (79)

### 1.5.4 Medical disorders

#### Epilepsy

A meta-analysis of people with epilepsy regarding the risk of drowning showed a 15- to 19-fold increase in risk as compared with a general non-epilepsy population. The increased risk is thought to be the result of seizures in aquatic environments. People with epilepsy, their relatives and other caregivers should be informed of the potential risk, so that death from drowning during a seizure could be prevented. (80)

In a US study of n=482 drownings, 5% of all drownings were interpreted as being due to epilepsy. Important preventive measures were summarised as: a) supervision of individuals when in aquatic environments, b) adequate seizure control and c) compliance with anticonvulsant therapy. The wearing of personal flotation devices is another important preventive factor for these individuals, as some victims were reported to have fallen off boats. (81)

### **Cardiac disease**

The most common cause of CA in Sweden is cardiac disease, with an overall reduction in survival at older ages. (82)

The general presence of cardiac disease in drowning deaths has been shown in several studies to range from 49-60%, making it a common finding. In victims older than 64 years, 84% had a known heart disease. (83-85) Myocarditis in otherwise healthy individuals has been found at autopsy and channelopathies such as Long QT syndrome (LQTS) and specifically LQT1 may induce lethal arrhythmias such as ventricular fibrillation or ventricular tachycardia during swimming. (36, 37, 39, 86)

### **1.5.5 Alcohol and drugs**

Drugs and specifically alcohol appear to play an important role in drowning, with reports of 30-80% of the studied populations showing findings of alcohol post-mortem. (87-91) The high rate of about 80% of blood alcohol levels was reported in accidental boating-related drownings in Finland in 1970-2000. (89)

The degree of increased risk following the intake of alcohol suggests that a person with a blood alcohol level of 0.10 g/100 ml (equal to 1 per mille) has an increase in risk of about 10 times compared with not drinking alcohol.

It is noteworthy that lower blood concentrations of alcohol are also related to increased risk. This correlation has not, however, been investigated to the same degree. The proportion of drownings associated with alcohol as the main cause of drowning is in the range of 10-30%. (87) There is poor epidemiological evidence relating to the role of alcohol with regard to the effect on swimming ability and risky behaviour.

Data on drugs other than alcohol as a risk factor for drowning are not mentioned in the literature to the same extent. However, Gorniak et al. reported the presence of illegal drugs (without the presence of alcohol) in only 3% of cases of unintentional drowning, with cannabinoids and cocaine as the most frequent and methamphetamine and phencyclidine (PCP) present in a few cases. In suicidal drownings, illegal drugs were present in 12% of all

cases, with cocaine most frequently present with a frequency of 67% in this subgroup. (92)

Data from Ahlm et al. showed that 38% of all autopsied drownings in Sweden during a period of 18 years (n=5,125) had alcohol in their blood, with a mean concentration of 1.8 g/l. In unintentional drowning, intentional drowning and unclear cases, the proportion of alcohol in the blood was 44%, 24% and 45% respectively. Psychoactive drugs, mainly benzodiazepines, were found in 40% of all tested cases, while, in the case of intentional drowning, the same proportion was 69%. Ahlm found illegal drugs in 10% of the tested material. (91)

In conclusion, the overall recommendation is to not enter the water or participate in aquatic activity after any use of alcohol or other drugs. (72)

## 1.6 Ethics in OHCA care

Resuscitation that is successful provides survivors with good quality of life in most cases. (69) However, the fact that the early forecast of survival is difficult and the evidence shows that 4-27% of victims end up in a vegetative state raises questions relating to the ethical considerations that need to be taken before starting CPR. (16)

The ERC states important principles of ethics in the guidelines from 2010. (93)

- **Autonomy**, the patient's right to refuse or accept treatment. Drownings can be both accidental and suicidal, the will of the victim is seldom known at the time of EMS arrival.
- **Non-maleficence**, meaning that health-care personnel should do no further harm and restrain from resuscitation where survival is apparently impossible.
- **Beneficence**. Health-care personnel should give the kind of care that most benefits the individual patient. Sometimes this means resuscitation, sometimes not.
- **Dignity and honesty**. The importance of giving care with dignity and providing honest information without avoiding important facts of the case.

### **1.6.1 When to start CPR?**

Resuscitation should not be initiated if it is against the patient's will or if the intervention is futile. The balance between risk and benefit is difficult to evaluate at the accident scene, as there might sometimes be a possible reversible cause of the arrest such as hypothermia. (69)

The exact time of submersion is often unknown, as is the potential neuroprotective effect of cold water temperature. These factors could widen the window of opportunity to commence CPR. In practice, CPR should be initiated if the submersion time is less than 60 minutes, but, in cold water, this time could perhaps be extended to 90 minutes, whereafter neurologically intact survival seems unlikely. A decision to resuscitate is often based on a little information and this lack of information causes CPR to be started on wider indications and with extended time limits. (15)

### **1.6.2 When to stop CPR?**

Cardiopulmonary resuscitation in OHCA due to drowning should be prolonged for more than the generally accepted 20 minutes of sustained asystole in OHCA with a cardiac aetiology. This is due to the probable asphyxial aetiology in drowning and to the potential effects of hypothermia. As many drowning victims are children, it is also generally accepted that CPR is initiated on wider indications and that it continues for a longer period of time both in the pre-hospital setting and in the ED. (69)

### **1.6.3 Family presence during OHCA care**

Many relatives wish to be present during resuscitation. Family members might also be the ones performing bystander CPR prior to EMS arrival. Of those people with experience of being present and having to perform CPR, more than 90% wish to do it again if the situation is repeated. The presence of the relative should be encouraged, but the decision has to be made individually. Health-care personnel should be assigned to explain the interventions that are given and to provide general comfort and care to the relatives. Family presence appears to be a way of accepting the outcome in the long term. (69, 94)

## 1.7 Knowledge gaps

Pre-existing knowledge gaps in the field of OHCA due to drowning appear to be as follows.

- In overall terms, few studies of larger cohorts of OHCA due to drowning patients in terms of characteristics and outcome
- No knowledge of delays during surf rescue from OHCA due to drowning
- Limited knowledge of the quality of CPR in surf lifeguards
- No knowledge of the quality of CPR and effect of fatigue as performed by surf lifeguards
- No knowledge of the characteristics and outcome of drowning victims as reported by rescue and fire services
- No evaluations of the impact of rescue-diving units in OHCA due to drowning
- Limited knowledge of the occurrence and characteristics of cardiac disease in OHCA due to drowning in relation to the victim's intent
- Limited knowledge of the characteristics of intentional drowning cases
- Limited knowledge of changes over time in characteristics and outcome of patients suffering from OHCA due to drowning
- No evidence of the impact of new guidelines for CPR on the outcome in OHCA due to drowning

## 2 AIM

The overall aim of this thesis was to describe characteristics and outcome after OHCA due to drowning.

The aim of each of the papers included in this thesis was as follows.

- I. To describe the characteristics and survival of patients suffering from OHCA due to drowning as compared with OHCA caused by a cardiac aetiology outside home in Sweden. Furthermore, we aimed to evaluate factors of importance for survival.
- II. To describe the delay during surf rescue and compare the quality of CPR, before and after exertion, in surf lifeguards.
- III. To describe the characteristics associated with rescue from drowning as reported by the Swedish fire and rescue services (SFARS) and their association with survival from the Swedish OHCA register
- IV. To determine the prevalence of cardiac disease and its relationship to the victim's probable intent among patients with OHCA due to drowning in Sweden
- V. To evaluate changes in characteristics and survival over time in OHCA due to drowning in Sweden and to describe factors of importance for survival

## 3 PATIENTS AND METHODS

### 3.1 National register for out-of-hospital cardiac arrest

The Swedish out-of-hospital cardiac arrest (OHCA) register has been active since 1990 and is a joint venture between the Swedish Resuscitation Council and the Federation of Leaders In Swedish Ambulance services (FLISA). Since 1993, the register has been funded by the Swedish National Board of Health and Welfare and today the register is funded by the Swedish Association of Local Authorities and Regions.

Reporting to the register is done by EMS clinicians by filling out a protocol immediately after a cardiac arrest event in which CPR and/or defibrillation was initiated by either bystanders or by the EMS clinicians themselves. The EMS clinicians can describe the cause of the CA in the following ways; cardiac aetiology, lung disease, accident, intoxication, suffocation, suicide, sudden infant death syndrome (SIDS), drowning, other cause and unknown cause.

The protocol with all its included forms was earlier sent to the medical director who in turn sent a copy to the central register in Gothenburg. Reporting has increased over the years and, in 2007, the standardised protocol became web based. For 2010, a total of  $n = 4,514$  reports came in to the register and the total number of reports in the register from 1990-2010 consisted of  $n = 56,780$  cases. The register now (2013) has a coverage of more than 90% of all OHCA cases and includes 100% of Sweden's EMS organisations.

### 3.2 Helsinki Declaration

The reporting of OHCA's due to drowning in the Swedish OHCA Register is done without prior information or informed consent due to the nature of the event. The OHCA Register is, however, expected to follow the general recommendations of the Helsinki Declaration. These ethical guidelines of research include the administration of information, informed consent and the way data are documented and kept by the researcher, amongst others. (95)

Even though most of the reported victims die as a result of the event, there is ongoing activity and efforts are being made in the follow-up of all survivors,

informing them and asking for approval of their inclusion in the register. All survivors are informed of their participation in the register and, if they so wish, they are erased from the data logs. All information, data files and storage of data are kept safe within the research department. Results are presented at group level with no opportunity to trace individuals.

### **3.3 Paper I**

Data for analyses included in Paper I are based on retrospective reports from the Swedish OHCA Register in 1990-2005. All patients who were categorised by EMS clinicians as OHCA due to drowning during this time period (n=255) in which CPR was initiated and who were not EMS witnessed were included. These patients were compared with those with a cardiac aetiology outside home (n = 7,494).

All statistical analyses were made using SAS software. For analyses of age and delays, Fisher's non-parametric permutation test was used, while, for dichotomous variables such as differences in gender distribution between OHCA due to drowning and cardiac aetiology, Fisher's exact test was used. In the multivariate analysis calculation of odds ratio, a stepwise logistic regression was used. Tests are two-sided and considered significant if they have a p-value of less than 0.05.

#### **3.3.1 Ethical approval and considerations**

The regional ethics committee of Gothenburg approved general retrospective research being done at the OHCA Register in 2000-11-09 (Dnr: A2 1670/00). The committee stated that, if information was to be obtained from other sources, i.e. follow up from primary health-care institutions, for example, written, informed consent was to be obtained from all survivors of the OHCA. No specific applications were handed in for this study. Nor was there any follow-up of other data or journal documents that were requested as part of the study.

All the patients who survive CA are informed that they are registered in the OHCA Register and which personal data it contains. They are also told that participation is free and that all data will be erased if they so wish. The author's opinion was that the general ethical approval from 2000 applied to the present study and that none of the included cases could be recognised or suffer from this, as the data are presented in large cohorts. All the data were kept and stored securely by the researcher.

## 3.4 Paper II

Surf lifeguards from Tylösand surf lifesaving club (SLSC), in Sweden patrol the beach off Halmstad and watch bathers for a period of eight weeks every summer. Four of these weeks were randomly selected and the enrolled lifeguards were asked to participate in the study. All the enrolled lifeguards during these weeks chose to participate with informed consent,  $n = 42$ . However, two of them were unable to participate due to health issues and were excluded, leaving  $n=40$  subjects for evaluation.

The lifeguards were asked to perform two tests, the first of which was single-rescue CPR on a manikin for 10 minutes. Data on CPR quality were recorded using a Resusci Anne manikin and the Laerdal PC skill-reporting system software version 2.2.1

The second test consisted of a primary rescue of a simulated unconscious victim, weight 80 kg, placed 100 metres from the shore. The lifeguards had to swim out, secure the victim, tow the victim back to shallow waters (50 metres from shore) and indicate by raising a hand that mouth-to-mouth ventilations could be administered. The victim was then brought ashore and CPR was again initiated on the manikin, single rescue for 10 minutes.

The conditions were calm and wind speed or wave height did not impair the results in any way. The distances were controlled and measured on a daily basis. The water conditions were chosen so that the protocol of this study could be used and the conditions reproduced in other surf lifesaving organisations around the world. The participants did not receive feedback on their performance until after the study period so that there would be no bias between test one and two or between subjects.

All statistical analyses were made with SAS software.

Pearson's correlation analysis was used to analyse the correlation between the two tests. The unpaired test was used for comparisons between genders and for continuous variables such as delays. Fisher's exact test for dichotomous variables was used for differences between rested and exerted lifeguards. The tests are two-sided and considered significant if the p-value is less than 0.05.

### 3.4.1 Ethical approval and considerations

An application was handed in to the regional ethics committee of Gothenburg for this observational manikin study. The opinion of the scientific secretary

of the committee on 22 June 2009 was that the area of this research was not under the governance of the law of ethics in research and that it should therefore not be considered by the committee. The decision was given via personal communication with the scientific secretary.

However, the authors discussed eventual ethical dilemmas associated with surf lifeguards participating in the performance of lifesaving in the sea. The united opinion after discussion and after talks with the surf lifesaving senior officers was that these individuals were well trained for the tasks and that the conditions in which the tests were to be executed were very calm and thereby safe. In addition to this, there was back-up at all times with rested surf lifeguards and rescue equipment at the beach providing vigilance during the tests.

Further, we expected that the testing of CPR skills could be embarrassing for individuals who were perhaps unable to perform so well in the skills of water lifesaving and CPR, procedures that are their main tasks on the beach. We were therefore additionally cautious about not letting any other test subject or other person in the organisation auscultate the tests or study any results. Written informed consent was obtained from each participant. All the data were kept and stored securely by the researcher.

### **3.5 Paper III**

This study is based on retrospective data reported to the Swedish Civil Contingencies Agency (SCCA) Register from SFAR. This was compiled with data reported to the OHCA Register from EMS organisations in Sweden at national level between 1996-2010. The local SFAR officer reports rescue characteristics and actions taken, as well as weather conditions, to the SCCA soon after the incident. Data on rescue diving are only available from 2005 and onwards.

Emergency Medical Service clinicians report characteristics from advanced CPR interventions given immediately after the event. Cases from the OHCA Register that matched cases reported to the SCCA were included in the study, i.e. cases in which the EMS and fire services were dispatched to the same event,  $n = 250$ .

For statistical analysis, SAS software was used. The Mann-Whitney-Wilcoxon test was used for differences in continuous variables, i.e. time, age, temperature, diving depth and so on. Fisher's exact test was used for

dichotomous variables, i.e. gender, witnessed status, shockable rhythm and so on. The tests are two-sided and considered significant if the p-value is less than 0.05.

### **3.5.1 Ethical approval and considerations**

The regional ethics committee of Gothenburg approved the application for Study III and Study V on 2 March 2011. (Dnr: 271-10). Both studies are retrospective register studies based on the OHCA Register and the SCCA Register (Study III) and the OHCA Register (Study V).

Data on characteristics and survival are presented in cohorts. Presentations of survival showing individual cases are not traceable to either person or place. All the data were kept and stored securely by the researcher.

## **3.6 Paper IV**

The data in Paper IV are based on autopsies reported to the National Board of Forensic Medicine (NBFM). All drowning victims in Sweden who underwent an autopsy in 2002-2011 are included in the study,  $n = 2,166$ .

For analysis of drowning characteristics, all cases reported to the OHCA Register that matched the NBFM Register, where CPR was initiated but where the victim died, are included,  $n = 272$ .

For statistical analysis, SAS software was used. The Mann-Whitney-Wilcoxon test was used for differences in continuous variables and Fisher's exact test was used for comparisons of dichotomous variables. A significance level of  $p < 0.05$  was used.

### **3.6.1 Ethical approval and considerations**

The regional ethics committee of Gothenburg approved the application for Study IV on 28 December 2010 (Dnr: 666-10). The data are only presented in cohorts and all the data were kept and stored securely by the researcher.

### **3.6.2 Paper V**

Study V describes changes over time in all OHCA due to drowning reported to the OHCA Register in Sweden. The data are presented between 1992-2011 and are clustered into five-year intervals for comparisons. A total of  $n = 494$  reported drowning cases are included in this study. For statistical analysis, SAS software was used. The Mann-Whitney-Wilcoxon test was used for

differences in continuous variables and Fisher's exact test was used for comparisons of dichotomous variables. A stepwise logistic regression was used for multivariate analysis. The tests are two-sided and considered significant if the p-value is less than 0.05. A stepwise logistic regression was used for multivariate analysis.

### 3.6.3 Ethical approval and considerations

With regard to the principles applied regarding ethical approval for Study I, the same approval from the ethics committee was used for this study, dated 9 November 2000 (Dnr: A2 1670/00).

### 3.6.4 Statistical analysis

Throughout Papers I-V, most variables described are on nominal scale level (gender, shockable rhythm, witnessed status and so on). Interval scale level data (water temperature in Paper III) and quote scale level data (length, height in Paper II) are, however, also present in the analysis. All timedelays are logarithmised in the analysis. For the multivariate analysis in Papers I and V, a stepwise logistic regression model was used. Statistical analyses have been performed using the SAS software version 9.0 and above in all Papers I-V. An overview of statistical tests used is shown in figure 4.

	Paper I	Paper II	Paper III	Paper IV	Paper V
Descriptive statistics	X	X	X	X	X
Fisher's exact test	X	X	X	X	X
Unpaired T-test		X			
Paired T-test		X			
Pearson correlation		X			
Logistic regression	X				X
Mann-Whitney-Wilcoxon			X	X	X

Figure 4. Overview of statistical tests used in Papers I-V.

## 4 RESULTS

### 4.1 Paper I

A total of  $n = 40,503$  patients with OHCA were eligible for inclusion in this study. EMS-witnessed cases ( $n = 4,770$ ) and cases with missing data on cause were excluded ( $n = 2,790$ ). In the remaining  $n = 32,943$  cases, a total of 299 cases (0.9%) were judged as being caused by drowning by the EMS clinicians reporting the data. These were compared with those with a CA due to cardiac aetiology outside home,  $n = 7,494$ . Cardiac arrest due to drowning took place at home in 13% of cases,  $n = 37$ .

#### 4.1.1 Characteristics

Patients suffering CA due to drowning outside home differed from those with a less frequently witnessed CA of cardiac aetiology outside home in several ways. They had a lower mean age ( $44 \pm 26$  years) than victims in the cardiac group ( $70 \pm 13$  years) and they were less frequently witnessed (29% versus 74% in the cardiac group), see table 1. Witnessed status was also related to age, with fewer victims of younger ages being witnessed.

Shockable rhythm was rare in the drowning group, 8%, versus 49% in the cardiac group. The median delay from CA to calling for the EMS was five (2-10; interquartile range, IQR) minutes versus three (2-5) minutes in the cardiac group. The median delay from calling to the arrival of the EMS was longer than in the cardiac group, 15 (10-29) minutes versus 10 (7-15) minutes,  $p = <0.0001$ . There was a relatively high proportion of bystander CPR in the CA due to drowning population, especially in children, where 85% received bystander CPR.

	Drowning, n = 255	Cardiac etiology, n = 7494	p**
Age (years) (212, 7083) Mean ± S.D.	44 ± 26	70 ± 13	<0.0001
Gender (%) (242, 7148) Female	20	21	
Witnessed status (%) (216, 6903) Bystander witnessed	29	74	<0.0001
Bystander CPR (%) (241, 7229) Yes	57	52	
Initial rhythm (%) (233, 6790) Shockable rhythm	8	49	<0.0001
Interval (median, min) Call for—arrival of ambulance (243, 7106)	9 (5–18) <sup>b</sup>	6 (4–10) <sup>b</sup>	<0.0001
Cardiac arrest—call for ambulance (55, 4438) <sup>a</sup>	5 (2–10) <sup>b</sup>	3 (2–5) <sup>b</sup>	0.001
Cardiac arrest—arrival of ambulance (55, 4279) <sup>a</sup>	15 (10–29) <sup>b</sup>	10 (7–15) <sup>b</sup>	<0.0001
Survival (%) Hospital admission (251, 7390) One month (244, 7380)	28.7 11.5	21.2 8.8	0.006

<sup>a</sup> Only bystander witnessed cases were included.  
<sup>b</sup> 25% and 75% percentiles.  
\*\* p-value denoted if <0.05.

Table 1. Characteristics and outcome among patients suffering out of hospital cardiac arrest due to drowning and cardiac aetiology.

### 4.1.2 Survival

Survival was associated with a short EMS response time and age, with greater survival in younger patients, see Figure 6. Patients suffering from drowning at home were younger than those presenting with a CA from drowning outside home. The survival rate was, however, significantly lower in the CA-at-home cohort, 8%. There was no significant difference in one-month survival between CA due to drowning and CA with a cardiac aetiology, 11.5% versus 8.8%. In a multivariate analysis considering all parameters, only delay between calling for and the arrival of the EMS was shown to be an independent predictor of an increased chance of survival.

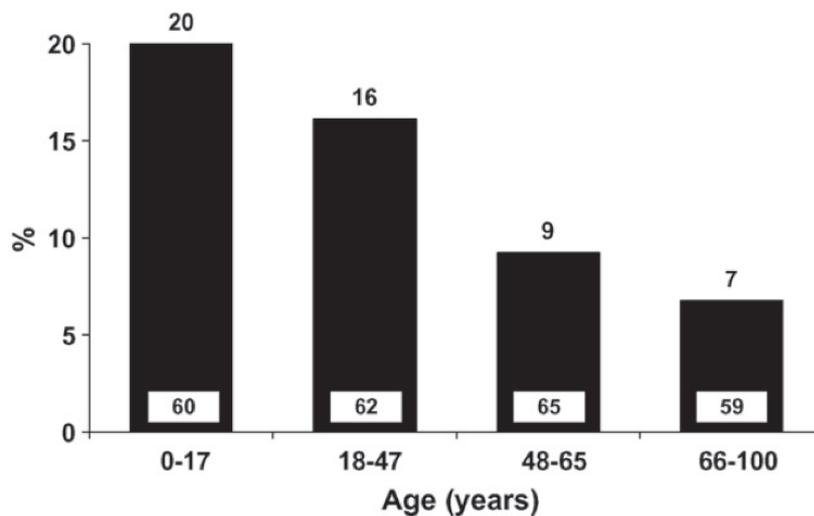


Figure 5. Survival from OHCA due to drowning in relation to age. Patients were divided into quartiles. The total number of drowning cases within each age group are presented in each column.

### 4.1.3 Conclusion

In all, 0.9% of all CAs in which CPR was initiated and which were reported to the OHCA Register were judged as being caused by drowning. The survival was not significantly different from that of CA judged as being caused by a cardiac aetiology. The only factor that was independently associated with higher survival among OHCA victims due to drowning was the EMS response time. There was a higher survival with a shorter delay from CA to the arrival of the EMS on the scene.

## 4.2 Paper II

A total of  $n = 42$  lifeguards who worked as voluntary lifeguards at the Tylösand surf lifesaving club (SLSC) were asked to participate in this study. They represented half the staff who were enrolled during the summer. Two lifeguards were unable to participate due to health issues, leaving  $n = 40$  subjects in the study.

The participating lifeguards had a median age of 26 years, 65% were men and their mean experience as lifeguards was three years. None of them was a health-care provider, but 60% were basic life support (BLS) CPR instructors.

### 4.2.1 Surf rescue delay

With a victim placed in the ocean 100 m from the beach, the median time from the beach to securing the victim was 83 seconds. The median time to starting ventilation was 155 seconds and to starting CPR back on the beach 258 seconds. It took twice as long to bring the victim back to shore as to reach him during surf rescue.

Men were significantly faster than women in all measured time intervals, except for towing back to shallower waters. Only 35% of the rescuers placed the victim correctly alongside the beach with the trunk and the head at the same level.

### 4.2.2 CPR quality

Measurements of CPR quality were based on ERC guidelines from 2005. The mean compression depth did not decrease significantly in rested lifeguards between 0-2 minutes (42.6+7.8 millimetres) and 8-10 minutes (40.8 +9.3 millimetres);  $p=0.2$ .

There was, however, a small yet significant decrease in compression depth in exerted lifeguards (44.2+8.7 at 0-2 minutes to 41.5+9.1 at 8-10 minutes,  $p=0.0008$ ). A small decrease in compression rate occurred in both rested and exerted lifeguards. The number of adequate compressions given was identical among rested and exerted lifeguards, 62% at 8-10 minutes respectively, see Figure 6.

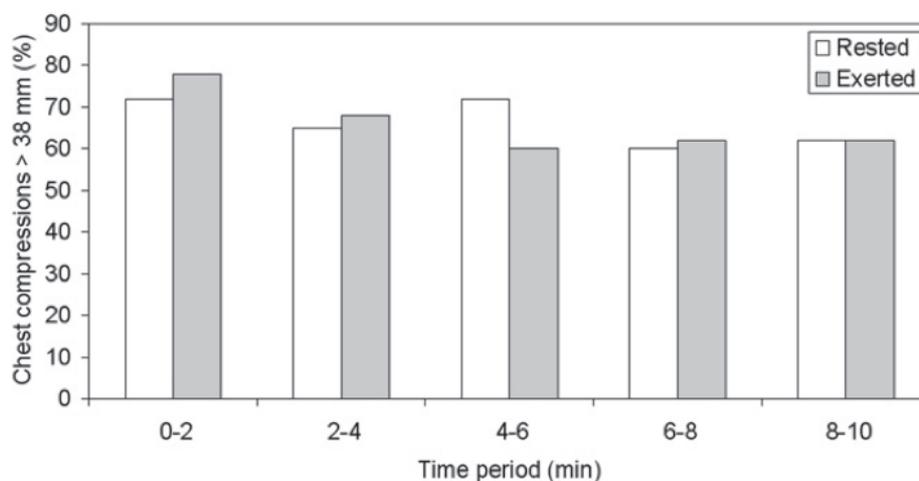


Figure 6. Figure showing quality of CPR and proportion of correct compressions in surf lifeguards as performed on a manikin. The white and grey bars represent rested versus exerted surf lifeguards respectively. Data divided into two-minute cycles.

Ventilation volumes increased significantly in both groups. Hand placement during CPR was correct in 98% of all compressions given and the overall mean hands-off time when administering ventilations was eight seconds.

### 4.2.3 Conclusion

In this simulation of a drowning, men were significantly faster during surf rescue and it took twice as long on average to bring the victim back to shore as to reach and secure him in the water. Half of all subjects administered compressions within the 2005 guidelines and the quality of CPR was identical before and after rescue, i.e. identical in both rested and exerted lifeguards.

## 4.3 Paper III

Between 1996 and 2010, a total of  $n = 7,175$  emergency calls in which the Swedish Fire and Rescue Services (SFAR) were dispatched due to drowning were included in the study. There were also  $n = 250$  OHCA cases from the OHCA Register that matched the SFAR protocol and from which survival was analysed.

### 4.3.1 Rescue characteristics

The median delay from CA, in witnessed cases, to calling for help was four minutes, as was also shown in Paper I.

The characteristics related to rescue in which the SFARS were involved and dispatched presented in the following way. The need for professional rescue was predominant in open water (80%), occurred between April and September in 68% of cases and in water with a temperature of < 10 degrees in 45% of cases.

Of all rescue calls, a rescue action only needed to be taken in about half the cases. In the other half, the victim was found on solid ground. The use of a boat and rescue board was common, while the use of a helicopter or rescue divers was less common. Free diving represented only about 1% (n=82) of all rescues with non-diving units.

### **4.3.2 Rescue-diving units**

A total of n = 210 cases in which a rescue-diving unit was dispatched were reported to the Swedish Civil Contingencies Agency, SCCA, during the time period.

The response from rescue-diving units did not differ significantly from the response times reported from stations using non-diving units. The median time was eight minutes, range 2-97 minutes. Calls to SFAR stations deploying rescue divers more frequently performed rescues in ports, open water and in warmer water than those SFAR stations without access to this intervention unit.

The drowning victims were found at a median depth of  $6.3 \pm 5.8$  metres. Drowning victims rescued by a diving unit were significantly younger (median of 40 and range of 24-54 years) than those rescued by non-diving units ( $59 \pm 42$ -73 years).

### **4.3.3 Survival**

Overall early survival to hospital admission from OHCA when SFAR and EMS units were dispatched was 23% and survival to 30 days 5.6%, n = 14. Nor were there any significant differences in 30-day survival between cases rescued by non-diving and diving units or between cases found in cold and warm water temperatures. The median water temperature was 15 degrees Celsius.

No survivors were found after more than 15 minutes of submersion in water warmer than 15 degrees. In water colder than 15 degrees, survivors were found after up to 40 minutes of submersion.

The cerebral outcome among survivors was good (CPC 1-2) in nine of 11 reported survivors. For two of the survivors, the cerebral outcome was poor (CPC 3). The non-surviving population did not differ markedly from survivors other than that they were slightly older.

#### **4.3.4 Conclusion**

Professional water rescue interventions were needed in about half of all drowning calls where the SFARS was dispatched. The majority of all OHCA cases in which CPR was initiated were found at the surface. Rescue diving took place in only a few cases and survival among them did not differ significantly from cases in which non-diving units were dispatched.

### **4.4 Paper IV**

A total of  $n = 2,166$  drowning cases were reported to the NBFM in 2002-2010. A total of  $n = 272$  OHCA due to drowning who did not survive the event but were reported to the Swedish OHCA Register were found and matched with autopsy reports from the NBFM.

#### **4.4.1 Characteristics**

The majority of all drownings were males (72%) with a median age of 58 (IQR 42-71 years). A probable contributory cause of the drowning event was found at autopsy in 21% of all cases. Coronary artery sclerosis and hypothermia were found to be the two most frequent possible contributory causes.

#### **4.4.2 Cardiac disease**

The group characterised as having a contributory cardiac disease were older than those that did not have a contributory cardiac disease, 71 years (IQR 55-77) versus 44 years (IQR 18-62).

A cardiac disease was found in 14% of all cases of accidental drowning and in zero per cent of cases with suicidal drowning. The proportion of cases with VT/VF was similar, regardless of the presence of cardiac disease, 7%.

#### **4.4.3 Accidents versus suicide**

More than half (55%) of all drowning cases were judged to be caused by accidents, whereas suicide was judged to be the cause in about a quarter (28%). The intent was unclear in 16% of all cases and murder represented a minority of 0.5%. Suicide was a more common cause of drowning in women

than accidents, see figure 7. Accidental drowning cases were younger than those with suicidal drowning, 45 years (IQR18-68) versus 59 years (IQR52-72).

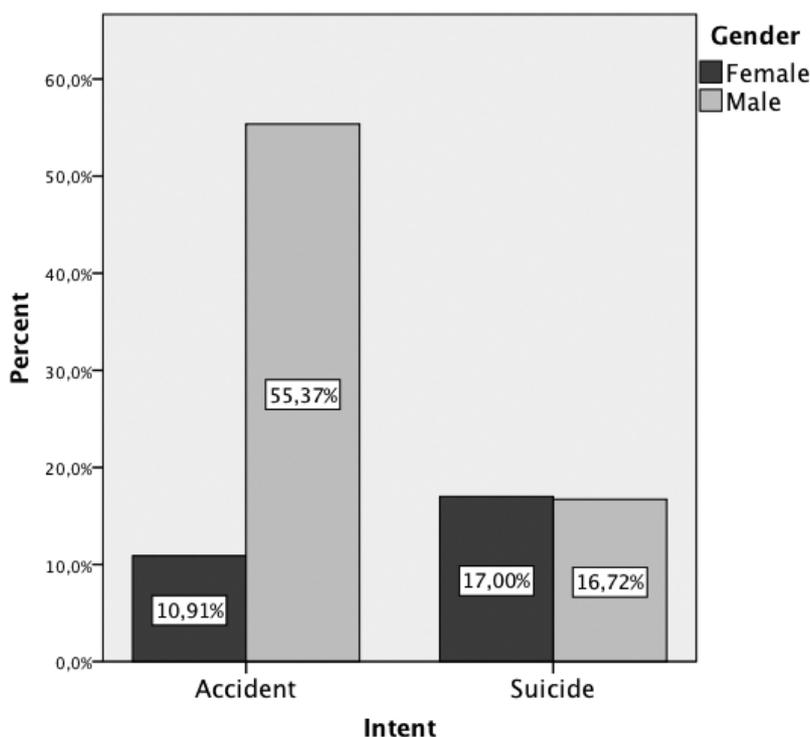


Figure 7. Mechanism of drowning (intent) distributed by gender n=1808.

#### 4.4.4 Conclusion

Among n = 2,166 autopsied drowning cases, more than half were considered to be accidental and less than one-third suicidal. Among accidents, a total of 14% were found to have a cardiac disease as a possible contributory factor, while this figure among suicides was 0%. The low proportion of cases with ventricular fibrillation was similar, regardless of the presence of a cardiac disease.

#### 4.5 Paper V

A total of n = 61,704 OHCA cases were reported to the OHCA Register between 1990-2011. Of these, n = 494 (0.8%) were judged to be caused by drowning. An average of 22.5 drowning cases a year were reported, with a slight increase over the years.

### 4.5.1 Changes over time

There were no significant changes over time for the following parameters: age, gender, witnessed status, shockable rhythm or place outside home. Bystander CPR prior to the arrival of the EMS, however, increased from 63% in the period 1992-1996 to 78% in 2006-2011 ( $p = 0.003$ ).

The median delay from collapse to calling for help in witnessed OHCA cases decreased from six minutes in the early period to three minutes in the later period ( $p=0.04$ ). On the other hand, the response time for the EMS increased in the later period.

### 4.5.2 Survival

Early survival to hospital admission increased from 24% in 1992-1996 to 36% in 2006-2011 ( $p=0.02$ ). Survival to 30 days varied between 6-16% but showed no significant change over time.

In a multivariate analysis, bystander CPR was not significantly associated with survival to 30 days, although, in a univariate analysis, those that received bystander CPR had a 30-day survival rate of 14.8% compared with 5.9% among those that did not ( $p=0.01$ ). The only parameter that was independently associated with higher survival to 30 days was delay from calling for help to the arrival of the EMS (OR 0.35;95% CI:0.15-0.77).

### 4.5.3 Conclusion

Over a period of 20 years in OHCA due to drowning, bystanders called for help at an earlier stage and administered CPR more frequently in the recent period. Survival to hospital admission has increased, but the delay from calling, to the arrival of the EMS has not decreased and still appears to be the most important factor for survival to one month.

## 5 DISCUSSION

### 5.1 Methodological weaknesses

There is generally a problem when it comes to interpreting existing databases in Sweden registering drowning cases, as each raises questions about the population that is actually described. All the databases used in this thesis have a varying and mostly unknown proportion of missing data and are also influenced by potential unknown confounders which introduce bias to the results in one way or another. In general, co-morbidity most definitely plays a role, as our different studies have different cohorts with different age variations between them. Knowledge of the characteristics of the missing proportion is limited and generalisability to the entire population is thereby limited.

The databases and statistics listed below are not co-ordinated and only one (OHCA Register) is based on parameters recommended in the Utstein style guidelines for the uniform reporting of data from drowning. (26)

Only the Swedish National Board of Health and Welfare (NBHW) databases (causes of death and patient register) present a fairly complete picture of the true incidence of severe cases of drowning in Sweden.

#### 5.1.1 Internal validity and reliability

The internal validity of data has limitations due to the fact that the source data have not been verified. Have we measured what we aimed to measure? Delay is an example of this, as this variable may differ between registers, between the dispatch centre and the EMS unit and even between dispatch centres and EMS or SFARS units in the same drowning case. There is uncertainty about the internal validity of data, if a witnessed arrest really was a witnessed arrest, as this is communicated and interpreted by the EMS clinician on the scene. Most register data and variables are based on the opinions of clinicians in different professions and not verified within the scope of these papers.

However, in subset analyses of the OHCA register in Gothenburg and Falun, not focusing on drowning cases, there was very high agreement between register data and source data. A number of variables were tested and agreement was more than 95% in all of them. (96)

Reliability is the credibility of measured variables, i.e. the extent or degree of agreement in the measurements over time and between reporting EMS

clinicians. There is uncertainty about the reliability of the OHCA Register, for example, and the question is how this could be evaluated in a meaningful way. The web-based protocol, with help sections and automatic controls of delays, has probably increased the conformity of data and thereby the reliability of the register since its introduction.

### 5.1.2 The Swedish OHCA Register

The OHCA Register presents cases reported by the EMS but represents only a minority, an estimated 10-15%, of all reported (to the NBHW Register) drowning cases occurring in Sweden each year. The majority of drowning victims are unwitnessed and die from the event with no resuscitative efforts being made. Some other victims are rescued at an early stage in a conscious state but may have aspirated water, are not reported to the OHCA Register but are still treated at the ED.

The OHCA Register also has a non-defined proportion of missing cases, as mentioned below. Nevertheless, although the data in this register represent only a minority of all drowning cases in Sweden, these reported data on OHCA due to drowning are the best source available for scientific evaluations presented at national level.

The data reported to the Swedish OHCA Register have improved from the start of the register in 1990 until recent years in terms of the number of reports registered. There has also been an increase in the number of EMS organisations included. At the start, about 80% of all EMS systems in Sweden's 21 counties reported data to the register. This continued until 2009, when 100% were included, as the protocol became web based.

However, there are several limitations when it comes to interpreting data from the register. Firstly, data are reported by EMS clinicians who are generally not physicians and do not have instruments properly to determine the exact cause of the cardiac arrest. The conclusion on cause is often an estimate based on the patient's signs and symptoms prior to the arrest, medication, relatives' description of the collapse and other circumstances providing information on probable cause.

Even though OHCA due to drowning appears to be an obvious cause at the scene, it is not impossible that the actual reporting could be falsely categorised as something else. Drowning could perhaps be reported as suicide, intoxication or cardiac aetiology, depending on how the EMS clinician interprets the situation and the intent of the victim. We lack information on how and if these false categorisations of cause are actually present in the material, causing a missing proportion of drowning cases.

There are most definitely several confounders that influence the data in this register. For example, hypothermia might induce a higher proportion of shockable rhythm than in normothermic cardiac arrest. Many drownings are hypothermic and water temperature or body temperature is not available for a multivariate analysis in the OHCA Register. Data on core body temperature on arrival at the ED are also difficult to find retrospectively, especially in the time period before web-based documentation.

Further, alcohol is shown to be present in many drowning cases. We know nothing about the way alcohol influences shockable rhythm, changes in body temperature or chances of survival in this data set.

Heart disease was found to be present in a proportion of drowning victims in Paper IV. We have no knowledge of the prevalence of heart disease in drowning victims registered in the OHCA Register. It is probable that variables such as shockable rhythm and survival are influenced by comorbidity, such as the prevalence of heart disease. Heart disease is common in the entire Swedish population, with a higher prevalence at higher ages. In 2010, the Swedish National Bureau of Statistics calculated that  $n = 440,000$  persons, i.e.  $4,672/100,000$  inhabitants, or about 5% of persons 16 years of age or older, lived with some kind of heart disease. Heart disease was found in about 30% of men 85 years or older. A total of 97% of people living with heart disease were older than 45 years of age. (97) The prevalence of unknown or asymptomatic heart disease in the population is probably high. A substantial proportion of older people live with arteriosclerosis in the coronary vessels, without any symptoms.

Trauma is another confounder that could have influenced our findings of survival and so on. Road traffic accidents with cars ending up in bodies of water or suicidal jumps from high altitude, bridges and so on into water add an extra dimension to the already severe assault on the human organism and the chances of survival. It is impossible to interpret whether the exact cause of CA was trauma (perhaps also reported as accident) or drowning without a coronary autopsy, which is sometimes not done or at least not followed up. After the introduction of the web-based system, it is, however, only possible to choose one cause of CA in the OHCA Register and not multiple causes.

Early survivors might not be included in this register. The chance of survival decreases with time and most of the survivors of drowning are probably found in the first minutes after initial submersion, before the arrival of the EMS. Early ventilation and/or CPR can be life saving (68) and the EMS will find a conscious patient. We know nothing about the number of patients who are missing in the OHCA Register who received initial bystander IWR/CPR and thereby achieved ROSC in which the EMS did not need to continue to

administer ALS. It can be difficult, even for the most experienced rescuer, lifeguard or EMS clinician already on the scene, to validate whether there has actually been “only” a respiratory arrest or a complete circulatory arrest. The proportion of drowning victims who were rescued in the first minutes after drowning is probably higher than that reported by the EMS in the OHCA Register. It is reasonable to assume that reports can be omitted. Data from the OHCA Register were used for the analyses of results in Papers I, III, IV and V.

### 5.1.3 OHCA Register – missing data analysis

Strömsöe et al. performed a study analysing missing cases in the OHCA Register between 2008-2010 on a population corresponding to one third of Sweden’s population (about three million inhabitants of a total of 9.5 million people). The aim was to describe differences in characteristics and outcome between reported and non-reported cases in the OHCA Register. (96)

Missing non-reported cases were found via local EMS case record forms and were thus subsequently added to the OHCA Register. Strömsöe et al. found a missing rate of 25% (n=800) where EMS clinicians failed to report the OHCA case to the register. In another study, Strömsöe et al. describe an increase in the reporting rate to the OHCA Register from 27 OHCA reports/100,000 inhabitants in 1992 to 52/100,000 inhabitants in 2011. (98) Missing cases which have been found in follow-up analyses have also been added retrospectively to the register and this follow-up of non-reported cases is currently more of a routine.

When comparing the missing cases (25%) with the correctly reported cases (75%), the former were older (69 vs 67 years,  $p=0.003$ ). They received bystander CPR less frequently (60% vs 65%,  $p=0.023$ ), but they had a higher survival rate (11.9% vs 9.2%,  $p=0.035$ ).

No significant differences could, however, be seen regarding the distribution of gender, initial rhythm, delay, place of cardiac arrest, witnessed status or time of day when the OHCA took place. (96)

The missing cases found by Strömsöe et al. consisted of both EMS-witnessed cases with early successful defibrillation and cases in which CPR was terminated at the scene by EMS clinicians, where the patient subsequently died. There is most definitely a selection bias in interpreting data from the OHCA Register, as missing cases represent 25% of the material. How this bias influences data analyses is still difficult to explain, even though Strömsöe et al. have given trends describing differences in age, bystander CPR and survival.

However, no bias analysis was conducted for specific causes of the cardiac arrest, such as OHCA due to drowning. It is still unknown how data on cardiac arrest due to drowning differ between correctly reported cases and missed, non-reported cases. The relative extent of missing reports of OHCA due to drowning as compared to the complete data set is also unknown. It is possible to speculate that, in comparison with other causes, the categorisation of OHCA due to drowning is more accurate and that fewer cases are incorrectly interpreted as having other causes, as signs of drowning are more obvious.

Knowledge of whether EMS clinicians' compliance with reporting OHCAs due to drowning is greater than in other causes of OHCA is limited. More research is also needed to evaluate how characteristics might differ between reported and non-reported cases of drowning in terms of age, gender, bystander CPR, initial rhythm, delay and ultimately survival.

Efforts should be made to simplify the documentation in the protocol, as single individuals who report CA do this no more than a few times a year and might forget the procedures in between. The automatic transfer of general data (date, ID, district, delays) to the OHCA Register from the EMS patient journal has been applied since 2008 and it is one way of enhancing the system and perhaps improving internal validity.

Further, there are reasons to assume that reporting has been more complete in recent years compared with the period at the beginning of the register. After the introduction of web-based reporting, in some parts, the in-data are automatically controlled. Examples include time registrations, as the arrival time cannot take place before the time of calling for the EMS, for example. Perhaps in the future, automatically wifi-based documentation from AED's could enhance indata to the register to some extent.

It is of the utmost importance that we are aware of the limitations of the OHCA Register in the form of omitted reports and the potential bias of results presented. On the other hand, the database is unique as a source of knowledge and it is the best one available for OHCA due to drowning in Sweden.

In conclusion, there is limited knowledge on how bias in the OHCA database influences the analysis of results in our Papers I, III, IV and V. Data from Strömsöe indicate a 25% missing rate, but today most of these cases are reported and added retrospectively. Furthermore, the differences between

correctly reported cases and the non-reported cases added subsequently appear to be minor. (96) Further research based on this knowledge should focus on validating data on OHCA due to drowning from the register.

#### **5.1.4 Swedish Civil Contingencies Agency (SCCA)**

The SCCA provides infrastructure and legislation for the SFARS and presents data based on rescue calls from Sweden's 290 municipalities on a yearly basis. The SCCA presents drowning statistics that are similar to those from the Swedish Lifesaving Society (SLS). The presented data are only accidental cases with drowning deaths. Data from the SCCA Register have been used for the analysis of results in Paper III and only consisted of characteristics of rescue from drowning based on  $n = 7,175$  rescue calls to the SFARS between 1996 and 2010.

It is probable that the proportion of missing data from this register is low. The senior officer at the fire and rescue department is obliged to document the rescue procedures during the same shift or at the latest during the following shift. As there is a follow-up from both the regional dispatch centre and from the SCCA in order to collect all protocols from calls, most data are probably collected. The SCCA validates incoming data on a yearly basis, excluding duplicate reports and obvious misstatements, as well as the misreporting of delays.

One potential confounder biasing these data on rescue characteristics could be judgement of water temperature due to ways of collecting this variable; some officers use thermometers on site, while others search national meteorological institute data on line. There might also be some duplicates when two rescue stations are called out to the same accident site.

Further, data on where the drowning victim was found, at the surface or below and at what depth, could be collected as secondary information from a bystander approximating the figure after a stressful situation. Data on rescue characteristics from the SCCA Register have been used for the analysis of results in Paper III.

#### **5.1.5 Swedish National Board of Health and Welfare (NBHW)**

The NBHW (ICD10 coding) causes of death register presents data on causes of death which are obtained from reports on death certificates by physicians from the NBFM. They are categorised as accidental drowning, intentional drowning, homicide or unclear cases. The coroner's expert opinion on cause of death is often an estimate based on data from different sources of

information, such as medical journals from the EMS and hospitals, police reports and the autopsy protocol. We know little on the differences between those included, having a complete ID number and those not eligible, not having an ID number.

One potential source of bias in this register appears to be inconsistent routines for describing levels of arteriosclerosis found in the coronary arteries during autopsy. No uniform scale or definition is used for concluding that the heart disease found during autopsy actually caused the drowning.

However, the coding of drowning cases is perhaps not always reliable due to the structure of the system in which drowning can be classified as the primary cause of death or sometimes as secondary to a myocardial infarction. What the cause of death will be in the end, drowning, drowning as a result of myocardial infarction or myocardial infarction, is probably up for discussion in many cases. A study from New Zealand showed that 18% were coded as injuries other than drowning when they were actually a drowning. The most common miscoding was traffic accident instead of drowning. There also appear to be differences in coding culture between countries. (10)

It is reasonable to believe that most drowning deaths are autopsied, but those cases that are treated in the ICU and die during the hospital stay are probably excluded, because relevant medical investigations have already shed light on the cause of the drowning. A report from the SCCA based on data from the register for causes of death in Sweden show that 89% of all drowning accidents 1997-2011 were autopsied. (99)

Data from the NBFM Register of causes of death have been used for analyses in Paper IV. The NBWH also keeps a patient register of in-patient care, but no data from this register were used for analysis in this thesis.

## **5.2 Adopting a Swedish drowning definition**

This thesis has not tried to challenge the existing definition of drowning but rather to adopt and spread it. The consensus decision on presenting a common drowning definition and uniform terminology in 2002 has clarified the drowning process somewhat. As drowning is a rare condition in the EMS and hospital ward, it is important to have a common understanding of the process for treatment, as well as the reporting and classification of the event. (26)

According to the definition, the drowning process results in a primary

respiratory impairment. The spectrum of this impairment is wide, ranging from a conscious, coughing patient to an unconscious, non-breathing, anoxic patient with water-filled lungs most often found in asystole. Treatments differ substantially between these two ends of the spectrum.

A central aspect of the definition is whether or not water has entered the airways. In many cases of rescue from rip currents, the victim might be exhausted after heavy swimming but has nevertheless not been involved in a drowning.

The Swedish terms for drowning do not as yet follow international definitions, which makes the interpretation of what has actually happened problematic. It is important to recognise drowning as a process. Regardless of outcome, the victim has been involved in a drowning if water has entered the airways causing respiratory impairment. A uniform Swedish translated definition based on the international drowning definition is needed to support health-care practitioners in both the pre-hospital and the in-hospital setting and to improve future research.

The lack of consensus and clinical use of the existing drowning definition has most definitely influenced the data collected in the above-mentioned databases in Sweden. This definition is not known in the general EMS organisations or in hospital settings in Sweden. The NBFM probably has the most experience and knowledge of describing the pathophysiology of drowning in relation to the definition.

The inability to adopt a drowning definition could have caused some cases to be interpreted as drowning even though they were not, such as immersed hypothermic victims found in life jackets, or, when the airways have been submerged, the incident could perhaps sometimes be falsely categorised as hypothermic CA rather than drowning.

The study by Wanscher et al. from the Praestofjord boating accident in Denmark exemplifies this dilemma most effectively. The authors do not clearly state that the victims had drowned, although many victims were found with their heads submerged. (14)

If the ILCOR definition of drowning (26) was fully implemented throughout the Swedish community and health-care systems, statistics of drowning cases would probably be different than they are at present.

## 5.3 What is the true incidence of drowning in Sweden?

Treated OHCA due to drowning reported to the OHCA Register represents only a minority of all the drownings occurring in Sweden each year. The majority of included drowning victims have probably been submerged for less than 60 minutes and are found in CA.

The Swedish Lifesaving Society (SLS) presents statistics from drowning at an early stage in Sweden and they are often referred to in the general media. In 1900, the SLS suggested 22 drownings per 100,000 inhabitants, comprising about 1,100 accidental drownings each year. In the mid 1950s, the ratio was down to 6/100,000 and, in 2011, 1.0/100,000 drownings per 100,000 inhabitants throughout Sweden according to the SLS. Today, the SLS presents drowning statistics of accidental drowning only found in media coverage. (100). Unclear cases, intentional drownings and survivors treated either as in-patients in hospital or in primary health care such as the ED are not included in SLS drowning statistics. No data from the SLS have been used in the analyses of results in Papers I-V in this thesis.

The most accurate source when examining the incidence of drowning deaths in Sweden is most probably the NBHW and its register of causes of death. (8) This register is compiled with data from the NBFM, police authorities and the health-care system, including the NBFM, on accidental, intentional and unclear cases. (99)

The National Board of Health and Welfare also registers in-patient care with ICD coding of non-fatal drownings in its national patient register. Excluded from these statistics are all drowning victims who are treated in primary health care or at the ED and who are most often discharged the same day as the event.

The true incidence of drowning in Sweden is still unknown, due partly to the fact that the ILCOR definition has still not been fully adopted and partly to the fact that there might be a miscoding in forensic reports and that drowning survivors treated in primary health care or at the ED are not reported correctly. Below is a figure describing all drowning deaths and all treated in-patient drowning survivors reported to the Swedish National Board of Health and Welfare in 2000-2011, see figure 8.

Based on the last five years (2007-2011), a median of  $n = 117$  drowning survivors have been treated in in-patient care each year and  $n = 191$  drowning deaths have occurred, consisting of accidents, unclear cases and intentional

drownings. In total, a median of  $n = 308$  drownings have occurred in Sweden each year. These cases represent at least most of the reported serious incidents. The data on in-patient care should be interpreted with caution. Nevertheless, there appears to be a decrease in overall drownings over a 10-year period. (8, 101)

It should be noted that some of the drowning survivors are most probably registered in both registers, as they might have survived to hospital admission but died during hospital treatment.

A recent overview of drowning deaths in Sweden 1997-2011 based on data from the NBHW register for causes of deaths show that drowning rates in women and children are generally low and that the decrease seen in drownings are mainly in men and elderly. In alignment with our paper IV this report show that drowning by suicide is more common in women than accidents. A total of  $n=3860$  drownings were reported to the register for causes of death over 15 years with 56% being accidents, 29% suicides, 14% unclear cases and 0,4% homicides. (99)

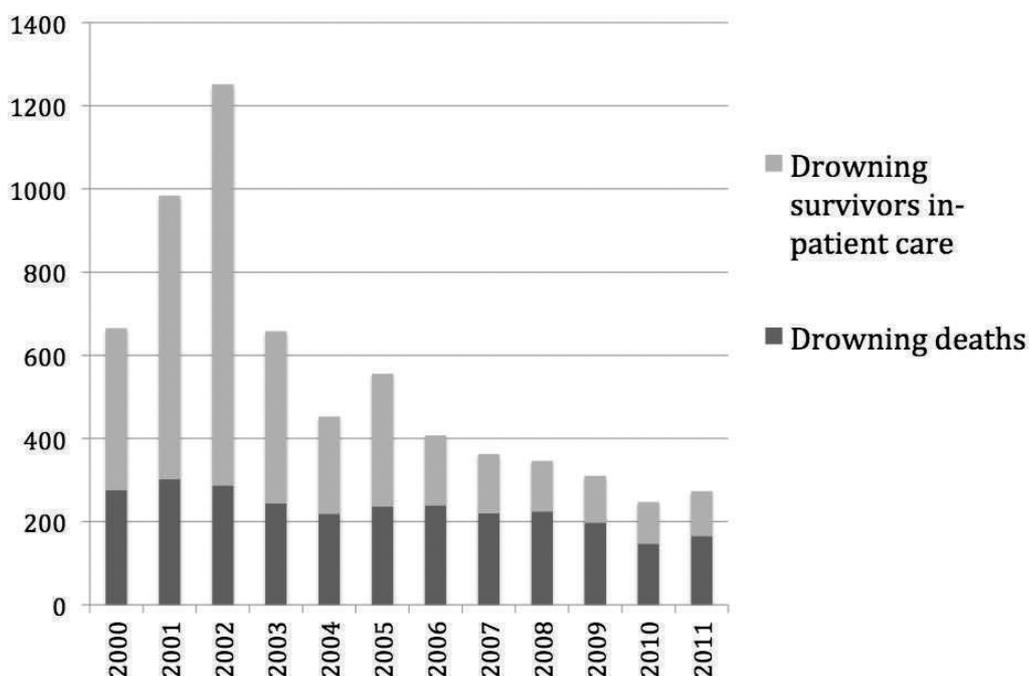


Figure 8. Swedish National Board of Health and Welfare. Data from the patient register of treated drowning survivors in-patient care (grey bars) and data from the register of causes of drowning deaths (black bars) in 2000-2011. ICD codes: V90, V92, W65-W74 X71, Y21.

## 5.4 Why is survival low after CA due to drowning?

Survival from drowning is primarily related to the time of hypoxia, with greater survival in conjunction with shorter submersion times. Early interventions with IWR and bystander CPR appear to be essential for survival. (68, 69)

Studies of the outcome of OHCA due to drowning which report survival rates differ significantly (7%-44%), probably due to large-scale heterogeneity in case selections and the reporting of data. (3, 19, 35, 102-104)

Some studies present outcome based on cohorts made up exclusively of patients admitted to hospital after OHCA due to drowning. Many drownings were excluded from analysis as they were declared dead at the ED. Our findings of overall survival to one month are, however, based on cases in which CPR and/or defibrillation were initiated either by bystanders or by the EMS clinicians. Survival rates to one month differed between papers in the present thesis: 5.6% in Paper III and 11.5% in Paper I. When examining changes over time in Paper V, survival varied non-significantly over the years between 6-16%.

Survival from drowning in Paper I was similar to the overall survival from OHCA as reported from the Swedish OHCA Register, which was 10.7% in 2011. (105)

We have most probably described different cohorts in Papers I, III IV and V from what initially appeared to be a uniform cohort of drowning victims. Different databases show different patient characteristics and do not include drowning victims based on the same criteria.

For example, the low survival in Paper III, 5.6%, could be due to the fact that the SFARS were dispatched to the “worst” cases. The early survivors with the best chance of survival had already been rescued by bystanders at the scene within the first minutes after drowning and only the EMS was dispatched to the scene. The interpretation of survival between papers should therefore be made with extreme caution, as the cohorts differ in terms of inclusion and therefore also in the characteristics of factors at resuscitation.

If someone experiences respiratory impairment, i.e. breathes water, there will be cardiac activity for a short time, probably one to two minutes (32) and IWR could be a life-saving intervention. (69)

The early survivors might not be included in the OHCA Register at all and at the other end of the spectrum, as found in Paper III, about one-third of

victims are submerged and are found at a mean depth of  $6.3 \pm 5.8$  metres. These cases might not be given the chance of surviving in communities that do not have access to rescue divers. It appears that, in submerged cases, when water rescue becomes technically more advanced, the time to the start of CPR increases and the chance of survival decreases.

The drowning victim appears to have disadvantages as compared to OHCA with a cardiac aetiology related to a low proportion of witnessed cases, prolonged EMS response time, positioning of/access to the body and the need for sometimes more technically advanced rescue procedures in submerged victims or for rescues in cold water.

On the other hand, the drowning victim is younger than the typical patient with an OHCA of cardiac aetiology, with less co-morbidity, perhaps making the chances of survival higher. Water temperature has been shown to be neuroprotective in case reports, (12, 13, 15) although this was not shown or verified in this thesis, where water temperature was tested in Paper III.

One explanation for the low survival rates could also be the different pathophysiology of drowning, where the victim initially suffers from a respiratory arrest with severe hypoxia resulting in a circulatory arrest. Inhaling water is a severe assault on the whole organism, including lung tissues.

The earlier onset of hypoxemia along with damage to the alveolar-capillary membrane, causing increased permeability with atelectasis and the wash-out of surfactant perhaps makes the chance of survival lower than in OHCA with a cardiac aetiology. (3)

In OHCA with a cardiac aetiology, a sudden arrhythmia often causes an initial circulatory arrest in which the hypoxia escalates during the subsequent minutes. (36)

Studies of cardiac channelopathies such as LQT1 indicate that some drowning cases could be due to a sudden swimming-triggered arrhythmia. In combination with generally higher co-morbidity in terms of heart disease in the older population, this might explain the finding of 8% VT/VF, measured 15 minutes after cardiac arrest in Paper I. Some victims happened to develop their cardiac-aetiology CA while in the water and thereby drowned. Hypothermia in cold-water drownings might also cause a VF/VT. Is it possible that high catecholamine levels might also induce VF/VT in OHCA due to drowning?

Drowning victims appear to be worse off than OHCA of cardiac aetiology, as they start off with severe hypoxia and are in desperate need of oxygen.

Ventilation is essential for this CA cohort. This is in contrast to studies of non-traumatic arrest (non-drowning), which suggest that survival is in the same range when comparing a traditional compression/ventilation ratio of 30:2 with compressions alone, without ventilations. (106, 107)

In conclusion, survival after OHCA due to drowning is probably still low because the cardiac arrest starts with severe hypoxia, a low proportion of drowning cases are witnessed, access to the victim is sometimes limited, bystander CPR is probably initiated at a later stage and the EMS response time is relatively long.

## **5.5 How is cerebral function among survivors of cardiac arrest due to drowning?**

This thesis has added limited additional knowledge on the quality of life among survivors after CA due to drowning. However, in Paper III, we found that, of all survivors for whom data was available on neurological function (11 of 14 cases), a total of 82% (n=9) had a favourable outcome, categorised as a CPC score of 1-2. In n = 2 cases (18%), the neurological outcome was poorer and both victims had a CPC score of 3. Data on CPC score are a harsh measure of neurological function and have only been documented in the OHCA Register since 2008, when the register became web based. The use of the CPC score is recommended in Utstein-style reporting of OHCA due to drowning, (26) but it has limitations in describing individual cognitive impairments and in distinguishing between mild or moderate brain injuries, making it a harsh measure of quality of life after CA. (108)

Neurological damage as a result of severe hypoxia is always worrying after resuscitation with ROSC after CA due to drowning. Cerebral function after CA due to drowning is the key outcome measurement, apart from survival. Although there are miracle cases of survival after prolonged submersion, most drowning victims die as a result of the event or suffer severe neurological damage at an early stage. (12, 13, 15, 68, 109)

According to Christensen et al. children might survive a drowning, but they do not seldom experience long vegetative periods in the ICU. Prognosis in terms of survival and neurological outcome is unpredictable at an early stage and submersion times might be unknown. This is a reason why both aggressive resuscitation and aggressive post-resuscitation care should be performed. (110)

Comparisons of data are sometimes difficult as databases differ between countries and many were not designed to produce scientific facts. Emergency Medical Service systems in different countries might treat drowning victims differently. Some physician-staffed EMS systems might withhold CPR at the scene, while other paramedic-, registered nurse- (RN) or emergency medical technician (EMT)-based EMS systems will transport all cases to the ED with ongoing CPR, with or without the use of mechanical compression devices. (16)

Yet others who survive to one month but subsequently die days, weeks or years later, perhaps after a vegetative state, are not included in SLS or SCCA drowning statistics and they are described as positive cases showing survival. (16)

In a severely limited set of material, Szpilman presented data differing from our findings, showing that 50% (n=2/4) of the survivors of non-in-water resuscitation, NIWR, developed severe neurological damage as compared to 38% (n=6/16) in the group receiving in-water resuscitation, IWR. (68) In Paper III, we had an unfavourable outcome (CPC score 3) in two of 11 victims, 18%.

However, as in our Study III, factors influencing these data are a small population sample of survivors (n=46), many excluded cases related to missing data and differences in CPR duration times with a mean of only seven minutes in the group receiving IWR in Szpilman's study. Mean water temperatures are probably higher in Brazil than in Sweden. Time to the start of CPR appears to be shorter in Szpilman's study, as there is a first responder (lifeguard) already on the scene on the beach. The overall survival rate presented in the study was 26% as compared to 5.6-16% in our Papers I, III and V.

In the IWR group, survival was as high as 53%, raising arguments that a CA might not always have been present at the time of rescue, related to difficulties in evaluating breathing and circulation in water. Szpilman's good results might be explained by the rescue being performed at an earlier stage. Furthermore, the median age was lower, 17 (9-31) years, in Szpilman's study as compared to 57 (38-73) years in our SFARS study. (68) Co-morbidity is more frequent at higher ages, which might influence comparisons.

Eich et al. reported data similar to those reported by Szpilman in a study of n=12 drowned children, where three of five survivors remained in a vegetative state, after a median submersion time of 25 minutes (range 15-40 minutes), mean water temperature 11.2 ( $\pm$  5) degrees. (71)

In overall terms, the data from Szpilman's study have nevertheless served as a background for recommending IWR to be performed in both deep and shallow water as a way of interrupting the ongoing hypoxemia. (69)

When it comes to submersion times, Szpilman confirms our findings when presenting a cut-off point at 14 minutes of submersion, after which every victim died or developed severe neurological damage. This is similar to our findings of no survivors after 15 minutes of submersion in water warmer than 15 degrees. The data from Eich et al. are slightly more positive, due perhaps to lower water temperatures and victims having a lower median age. (71)

Survival from drowning in warm water has been reported in the literature, but the submersion time is often unknown, i.e. the drowning is unwitnessed or the time of submersion is not known. This highlights the complexity of achieving survival after drowning in warmer waters and relatively short submersion times. (111)

When it comes to post-arrest care, therapeutic hypothermia has shown an increase in favourable neurological outcome when inducing hypothermia to 33 degrees in survivors of CA in the ICU for 12 hours. (48, 112). However, these studies did not include patients who had suffered an OHCA due to drowning.

## **5.5 Characteristics among patients with OHCA due to drowning**

### **5.5.1 Gender**

Papers I and V and, to some extent, also Papers III and IV give an overview of the reported patient characteristics in OHCA due to drowning. It should be remembered, however, that the descriptive statistics are only subsamples of the entire drowning population, with each paper describing a subsample and its specific perspective.

Males were over-represented in overall drowning statistics, with about 70-80% of all events involving men, as seen in Papers I and V. Males were also involved in the majority of accidental drownings, Paper IV. However, when comparing accidents with suicides in Paper IV, we found that women suffered from suicidal drowning more often than from accidental drowning, the same was found in a report from the same dataset of causes of death in Sweden 1997-2011. (99) The differences in gender between accidents and suicidal intent are difficult to explain. We can only speculate that men are

more exposed to aquatic environments with different behaviours, causing a higher proportion in the accidental cases.

### 5.5.2 Age and witnessed status

The data from Paper I showed that the drowning victims found in CA were significantly younger than in OHCA with a cardiac aetiology,  $44 \pm 26$  years versus  $70 \pm 13$  years.

Interestingly, we found differences in age between papers. Papers III and IV appear to describe a different, generally older, cohort of drowning victims than Papers I and V. There was, however, one exception in Paper III – victims eligible for rescue diving, who were significantly younger than those not eligible for rescue diving.

The differences in age between papers are probably due to the fact that we describe small, different cohorts of the total population of OHCA due to drowning. We fail to present a uniform cohort of drowning victims throughout Paper I and Papers III-V. A uniform database on drowning, including characteristics from every part of the chain of survival and from the NBFM, would enhance the validity of data. If all data on drowning victims were gathered in the same database and if data from the different registers were validated and followed up, it would be easier to present a truer picture of the characteristics of the cohort.

The cohort of drowning victims presented in Paper III appears to be worse off than those in Papers I and V. The cohort presented in Paper IV represents a larger perhaps more true proportion of drowning cases than those in Papers I and V, due to the fact that most drowning victims die as a result of the event and most of them are forensically examined.

Survival as presented in Paper I was also related to age, with a significantly higher survival rate in younger patients. These differences appear reasonable, due to increasing general co-morbidity in an older population. These findings are in agreement with Grmec et al. and Donoghue et al. who report higher survival at younger ages. Grmec et al. presented a mean age in survivors of 39 years and in fatal cases of 57 years. (35, 102)

Witnessed status in Paper I was related to age, with a higher proportion of witnessed cases in older age groups. Children aged 0-17 years who had the highest survival had the lowest proportion of witnessed cases, only 18%. Lack of supervision is an expected and reasonable explanation of the low number of witnessed cases. This low number of witnessed child drownings is

confirmed by Quan et al. who report 28% witnessed drownings in children 0-4 years old. (83) A low proportion of witnessed cases is also confirmed by Grmec et al. who reported 28% witnessed drownings. (35)

Both witnessed status and age differ from OHCA with a cardiac aetiology in which both parameters are higher. These deviations might counteract each other and thereby explain why the overall survival appeared to be similar among patients with OHCA due to drowning and patients with OHCA with a cardiac aetiology.

### **5.5.3 Shockable rhythm**

In Paper I, 8% of victims were found in VF/VT when rhythm was assessed on the arrival of the EMS a median of 15 minutes after cardiac arrest. This is similar to recent findings by Dyson et al. showing that shockable rhythm in OHCA due to drowning was a positive predictor of survival, with a total of 6% found in VF/VT. (113)

The multivariate analyses in Papers I and V did not show that shockable rhythm was a significant predictor of survival. Perhaps the proportion of VF/VT is higher in cases of hypothermia, which was shown to be present as a possible contributory cause of death in Paper IV. Hypothermia itself could be a confounder, altering the interpretations of survival as compared to VF/VT in CA with a cardiac aetiology. We speculate that hypothermic OHCA due to drowning might be more of a problem, as access and the start of CPR in cold winter conditions are perhaps difficult.

The proportion of patients found in VF/VT might be higher if the rhythm was assessed at an earlier stage. Public AEDs could perhaps provide this information in the future and perhaps also be a life-saving intervention in patients with OHCA due to drowning presenting with a shockable rhythm. Public pools are often situated near other public facilities and are visited by a large number of individuals. In addition to the fact that a proportion of drowning victims are found in VF/VT, this appears to be an incentive to have an AED nearby.

## **5.6 Can we define risk individuals?**

There are some known risk factors for drowning, such as alcohol and epilepsy, as well as some less known and probably some completely unknown to science at this stage in time. Children appear to run a high risk of drowning due to immature behaviour and poor swimming ability. Few cases

of drowning in the age group of 0-17 years were witnessed, as shown in Paper I.

The effect of swimming ability on drowning incidence is not yet fully understood. For children, a common knowledge of water safety and swimming lessons might prevent drownings. (76) This appears to be a very important intervention in LMIC, where families live by and come from a water environment. This is also where most global drownings occur. (3) Many lives and life-years could be saved by preventive efforts in the community worldwide. (2)

Cardiovascular disease was found to be a possible contributory factor to death in 14% of cases in Paper IV, perhaps contributing to or explaining some events in the drowning population. In general, co-morbidity and the presence of coronary arterial sclerosis increase with age and studies by Kido et al. Quan et al. and Papadodima et al. confirm that cardiovascular disease is a common finding in elderly drowning victims. (83-85)

Alcohol is known to increase the risk of drowning by increasing risky behaviour and general disorientation, impaired swimming ability and heat loss when immersed in water. The risk of drowning is increased about ten-fold following the intake of alcohol. (87) Alcohol as a confounder was excluded in Paper IV due to the large proportion of missing data. Ahlm et al. have, however, shown from the same data set that alcohol was a possible contributory factor to accidental drowning in 44% of cases, 24% in suicide cases and 45% in unclear cases. (91)

Although perhaps rare, Wisten et al. showed that arrhythmias such as LQT1 could be found in up to 20% of family members during screening in families where a relative have already suffered a OHCA. (39) Arrhythmias such as LQT1 are not seen during general autopsy and relatives are unaware of the potential risks of bathing, better diagnostic possibilities in the future might perhaps prevent such drownings.

How swimming ability and cardiac disease interfere with drowning is still in principle unknown. A recommendation that swimming should, for example, be prohibited after a certain age is much too vague and even provocative.

## 5.7 CPR in OHCA due to drowning

We know little about the quality of bystander CPR performed in OHCA due to drowning. Ventilation is essential for survival, airway management is also difficult and more advanced interventions such as a suction unit, oxygen and

intubation may be needed in order efficiently to oxygenate the drowning victim. (28)

In clinical in-water practice, it is not as easy to evaluate signs of life such as consciousness and normal breathing as it is in on-land conditions. Perhaps the rescuer should perform the initial five ventilations in a more powerful manner in order to get the chest to rise, oxygenating the blood and tissues, and to clear the airways from liquid? This would also increase the risk that the airway pressure will exceed 35-40 mm/hg, which increases the risk of air leaking to the stomach during ventilation. Paper II showed that ventilation volumes were high and even increased during the time that CPR was performed. These high-volume ventilations are not in accordance with guidelines and could perhaps affect survival in one way or another. The dilemma appears to be to maintain an airway pressure that is high enough to oxygenate the drowning victim during ventilation without simultaneously administering excessive tidal volumes causing gastric inflation.

Case reports and the general pathophysiology of drowning suggest that some victims suffer from laryngospasm. Furthermore, it is difficult for inexperienced bystanders to open the airway, causing regurgitation and increased inflation pressures. Finally, the chin might be slippery from water. Taken together, all these factors make airway management more difficult in OHCA due to drowning than in OHCA with a cardiac aetiology. (28)

In general CPR recommendations, the following should therefore be stressed.

- Early ventilations, IWR, when the rescuer's safety is ensured, could prevent a cardiac arrest and be essential for survival.
- Airway management is more difficult in drowning victims than in OHCA with a cardiac aetiology and additional training in airway management in both BLS and ALS algorithms is required.
- Many drowning victims are hypothermic and treatment should therefore continue until the victim has been warmed in a hospital environment.

### **5.7.1 Does bystander CPR increase survival?**

In the univariate analysis, bystander CPR was significantly associated with higher survival in Paper V, revealing a rate of 53-78% over a 20-year period. In the univariate analysis in Paper I, overall survival was 13% when bystander CPR was given versus 8% with no bystander CPR and, in Paper V, the corresponding figures were 15% and 6% respectively. Survival in Paper I was higher at younger ages, as was the proportion of victims receiving

bystander CPR compared with older ages.

The univariate analysis of bystander CPR as a factor associated with higher survival was based on  $n = 270$  cases in Paper I and on  $n = 468$  cases in Paper V. However, in the multivariate analyses, bystander CPR did not appear as a significant predictor of outcome. It is possible to speculate that the sample sizes were too small adequately to address the true impact of bystander CPR on survival in the multivariate analyses.

In a small set of material, Grmec et al. presented findings similar in many ways to those in our Papers I and V regarding gender, age, shockable rhythm, response time and neurological outcome. However, the proportion of suicide cases was high (69%), as was survival to hospital discharge (44%). Bystander CPR was associated with survival to hospital discharge in a univariate analysis, with 57% survivors in the group receiving bystander CPR versus 17% in the non-bystander CPR group ( $p=0.03$ ). (35) This was also confirmed by De Maio et al. presenting OHCA in children due to trauma, with 50% survivors in the bystander CPR population as compared to 15% survivors in the non-bystander CPR group. (104)

In a review of paediatric OHCA due to drowning, Donoghue et al. found that bystander CPR in submersion cases influenced survival positively in a univariate analysis but not in a multivariate analysis. (102)

There is limited knowledge about the exact delay between cardiac arrest and the start of CPR in our study and consequently the extent of the detrimental effect of a delay to the start of CPR. This needs to be taken into account in a more detailed way in the future. The problem is that the proportion of witnessed cases is so low, thereby creating difficulty in truly estimating the time of collapse. Our Paper II showed that surf lifeguards perform very well during prolonged CPR in a manikin model and that CPR could be initiated with a short delay in witnessed cases.

Kyriacou et al. showed that immediate resuscitation before the arrival of the EMS increased the chances of survival. Children who had good neurological survival were five times more likely to have received CPR before the arrival of the EMS than those that did not have a good neurological survival. (114)

Summarising the present knowledge, it appears that there is sufficient documentation to say that CPR started prior to the arrival of the EMS after OHCA due to drowning is associated with increased survival, as assessed from a univariate analysis. However, when various confounders are taken into account, the independent role of such an intervention in survival after OHCA due to drowning has not yet been adequately documented.

## 5.7.2 Delay to start of CPR

The delay to the start of CPR could probably be shortened if more OHCA due to drowning were witnessed than the 29% seen in Paper I. The time to the start of advanced CPR by the EMS clinicians could also be reduced if the time from CA to calling for help was shorter. A development in this direction was seen in Paper V, which reveals that the delay from CA to calling for help actually decreased from five minutes to three minutes in 2007-2011. This decrease could be due to developments in mobile phone technology, with telephones being accessible to a very large degree in recent years. However, the time from calling for help until the arrival of the EMS has increased. It is possible that an ageing population has stepped up the demands imposed on the EMS, making ambulance services less accessible today. Different traffic environments might also have caused an increase in the delay to the arrival of the EMS.

If more child drownings could be prevented and supervision was more efficient, the survival rates when a drowning actually occurred would most probably be even higher than today, due to the fact that bystanders could intervene at an earlier stage. The way bystander CPR influences long-term survival is yet to be examined in larger data sets in the future.

Based on the ERC guidelines from 2010 (69) and, as a result of the work during this thesis, the Swedish CPR council has released an algorithm on in-water ventilation and CPR in OHCA due to drowning. The aim of this algorithm is to activate resources already at the scene of the accident and to reduce the delay to BLS. As there were no survivors in Paper III after 15 minutes of submersion in water warmer than 15 degrees, and the median EMS response time was 15 minutes, this appears to be an intervention that could possibly have an effect on reducing the delay to the start of IWR/CPR, see appendix.

## 5.7.3 Future perspectives on bystander CPR

Although the multivariate analysis did not show significance for bystander CPR as a factor for survival, we speculate that Papers I and V were underpowered to address the question. It would be of great interest to re-evaluate the potential of bystander CPR as an important intervention for survival in a couple of years in a larger, perhaps doubled, data set.

We know little about the quality of CPR performed by bystanders prior to the arrival of the EMS. Future feedback devices relating to bystander CPR quality using accelerometers could perhaps provide and add knowledge to the

OHCA Register. The use of feedback devices during training has been shown to increase CPR quality. It may also be beneficial in regular practice. (115)

Witnessed status is one important variable when discussing early CPR. The sooner the drowning victim can be found, the sooner CPR can be initiated. With an increase in witnessed cases and a more widespread knowledge of CPR in the general population, there will probably be a further increase in bystander CPR, which might in turn increase survival from CA due to drowning. Increased awareness of the importance of parental vigilance, as well as more public swimming areas patrolled by lifeguards, could probably also increase the proportion of witnessed swimming-related drownings. Specific training programmes for lifeguards and fire and rescue services might enhance the chances of survival. An awareness of drowning-specific treatment in the general public could perhaps prevent rescuers from drowning, increase the proportion of IWR given and enhance the quality of CPR, so that compressions are not only performed in this category of CA cases.

The importance of bystander CPR for survival is stressed by the ERC. Cardiopulmonary resuscitation cannot be performed in the water and this then causes a delay until the victim is placed on solid ground or the equivalent. (69)

No efforts have previously been made in Sweden to differentiate CPR treatment algorithms between respiratory CA and circulatory CA in public training programmes. Nor does the ERC stress this in ways other than that rescue breaths should be given and a 30:2 ratio should be used. According to the Swedish OHCA Register, there has been an increase in overall bystander CPR from 33% in 1992 to 68% in 2011, a development that is positive and among the highest in the world and which might benefit OHCA due to drowning victims in the future. (105)

The effect of changes in guidelines on CA due to drowning is not shown in the literature. Longer series of compressions (30:2) have been shown to increase survival in large cohorts of CA, when the causes are not sorted. (63) The optimal ratio for the treatment of CA due to drowning is still unknown and the recommendations are adopted and applied using current knowledge of CA with a cardiac aetiology.

The pathophysiology differs in many ways from the CA with a cardiac aetiology and new approaches and possible interventions should be evaluated for this population. Large randomised studies comparing different ratios in CA due to drowning would be of interest, but they are difficult to perform

due to the low incidence. One interesting question is whether people in the community, already at the scene of the accident, would be able to distinguish between two algorithms, i.e. a circulatory OHCA algorithm and a respiratory OHCA algorithm. The pedagogic and implementational aspects of this need more attention in the future.

## **5.8 What is the importance of short EMS response time?**

Sweden has some 250 EMS stations, with about 600 units spread throughout the country handling close to one million calls every year, sometimes with long response times outside urban areas. (116)

Although there was a delay in the arrival of the EMS to drownings in relation to OHCAs of cardiac origin, the multivariate analyses in Papers I and V showed that the EMS response time was the most important factor for survival in overall terms. This finding is verified by Quan et al. in a study from the USA of  $n = 135$  paediatric submersions; they state that pre-hospital intervention with ALS is the most efficient in obtaining survival in OHCA due to drownings. (117) Moreover, Dyson et al. confirm our findings and conclude in a study from Australia of  $n = 336$  OHCA drownings that the EMS response time could increase survival. (113)

This is an important observation, as bystander CPR did not show any significant association with survival in a multivariate analysis. Basic life support (BLS) is immediately available, whereas ALS comes at a later stage. Which procedures or interventions cause the EMS response time to be the most important factor for survival as shown in Papers I and V?

Airway management is difficult in the drowning victim. Administering oxygen and early intubation are important in controlling the airway and optimising conditions for oxygenating the victim. Interventions like continuous positive airway pressure (CPAP) with positive end expiratory pressure (PEEP) are perhaps an important measure in alleviating serious hypoxemia in the spontaneously breathing victim. (28)

As many drowning victims are hypothermic and final treatment with the return of spontaneous circulation (ROSC) cannot be performed in the pre-hospital setting, CPR needs to be performed en route to hospital. In order to maintain good CPR quality during EMS transfer and to ensure the safety of the EMS clinicians on the way, mechanical devices can play a role. Adequate circulation can be maintained during transport and the safety of the EMS clinicians can be maintained as they can be seated using seatbelts. (69, 118)

Perhaps airway management is one of the most important key features in survival after OHCA due to drowning, a feature today only provided in ALS.

Rescuers providing BLS may be overwhelmed by the difficulty of ventilation with higher airway pressures, by regurgitation and by the slippery handling of the chin and chest during compressions.

We should look further into the interventions that are included in the ALS algorithm provided by the EMS that are beneficial to the drowning victim. A shorter EMS response time, meaning earlier ALS, may be difficult to accomplish due to logistical factors. However, some of these ALS interventions could perhaps be delegated forward in the chain of survival to competent rescuers in professions such as lifeguards and firemen. Airway suction units, oxygen administration and laryngeal masks are perhaps the key interventions that could result in additional lives being saved. Oxygen therapy is not generally used in standard BLS, but it is recommended in the treatment of asphyxial CA. Oxygen should be given if the saturation is below 94%, with the specific aim of achieving 94-98% of saturation. (70)

## **5.9 What is the role of lifeguards and community fire and rescue organisations?**

### **5.9.1 Lifeguards**

In Paper II, we found that surf lifeguards perform well regarding water lifesaving and in performing high-quality CPR over time. In a controlled setting, measurements of delay show that early ventilation could already be administered in the water within minutes. Our data can, however, not be generalised to apply to other professions or to the public, as the lifeguards are young, physically well trained, highly motivated and skilled in basic CPR. It is nevertheless an important finding for this profession.

Bjorshol et al. confirms our findings of high quality during prolonged CPR in a similar cohort of paramedics in Norway. The paramedics provided single-CPR for 10 minutes with different ratios with sustained high quality, fatigue was rare during the first two minutes of CPR. (119)

We can assume that the quality of CPR between individuals differ widely. Current guidelines with the recommendation of doing chest compressions for only 2 minutes before changing the person providing chest compressions is set to fit all circumstances. (69)

The model and methods we set up for testing in Paper II could also be copied and tested in surf lifesaving organisations worldwide in order to evaluate and develop clinical practice. Within the scope of this thesis, a Spanish research group copied our design as used in Paper II and published their results. Barcala-Fueros et al. confirm our findings that men were faster than women during surf rescue but show on the other hand that the exertion during surf rescue affected CPR quality. (120) One explanation of the different findings in this study is probably that they based the CPR guidelines on ERC 2010 using a compression depth of at least 50 mm in contrast to our Paper II based on guidelines from 2005 using 38-51 mm of compression depth.

Perkins showed that lifeguards were able to perform unsupported IWR, i.e. ventilation, in pool conditions while maintaining good quality. (121) An alternative to mouth-to-mouth ventilation in water could be a laryngeal airway mask, but IWR requires training in minimising the victim's further aspiration of water and minimising the delay to formal CPR. The feasibility of using interventions such as laryngeal airways in the water should be more thoroughly investigated. (122) When it comes to traditional adjuncts for use by lifeguards, mouth to mouth appears to be superior to a mouth to pocket mask or a bag-valve mask.(123)

These adjuncts were not evaluated in our Paper II. The study design was based on mouth-to-mouth ventilation. Further studies should evaluate the quality of CPR in lifeguards related to exertion, delay, the effectiveness of IWR and the use of different airway adjuncts for easier airway management.

Modell, however, describes substandard performance in the practice of lifeguard work. Of 97 pool drownings, the lifeguards only discovered 39% of the events, while the remainder were observed by bystanders. The lifeguards rescued the person from the water in 69% of cases and performed CPR in 70% of cases, whereas the remainder were treated by bystanders. (124)

Paper II was not based on real drowning events, a limitation that was due to the low incidence of CA on the beach at Tylösand. Prevention has probably been effective in reducing the number of drownings.

In conclusion, the training of lifeguards, their actual presence at the scene of the accident and their vigilance are all important when it comes to increasing the proportion of witnessed drownings and the potential to initiate early BLS. Surf lifesaving organisations should regularly evaluate CPR quality and delay time during surf rescue.

## 5.9.2 Community fire and rescue services

The Swedish Fire and Rescue Services (SFARS) is a national organisation that is governed by the SCCA and it plays an important part in lifesaving for drowning victims.

Paper III showed that there was a need for intervention from the SFARS in about half of all drowning calls to the dispatch centre.

As most drowning incidents occurred in relatively cold water of less than 15 degrees, appropriate safety measures and rescue equipment needed to be put into practice. Wetsuits, drysuits, boats and rescue equipment for ice rescue, among other things, play an important role and are standard in rescue procedures. Together with frequent training and vigorous routines, this presents a picture of an organisation that is well prepared for drowning rescues.

The SFARS plays an important role in CA due to drowning, as it is able to perform large-scale rescues so that the victim can be treated by the EMS at the scene of the drowning. However, the proportion of free diving was low. Early free diving is a low-cost, relatively safe intervention which could perhaps offer access to the victim in a large number of cases where rescue-diving units are not immediately available.

Paper III showed that, of 250 treated OHCAs, about 1/3 were found submerged. Professional rescue diving is only performed within the SFARS and in 18 of 290 municipalities. Municipalities with rescue-diving units were associated with a non-significant trend towards higher survival compared with municipalities without rescue-diving units. In addition to rescuing the victim and making the victim accessible to the EMS, the SFARS can also assist in ALS, during transportation, and in crowd control. One important task is also to perform a continued search for a body, long after the time that the chance of survival has run out.

Our findings suggest that professional rescue services sometimes get the worst cases, late arrival in drowning cases where the public has failed to perform a primary water rescue. The reasons for this could be low water temperatures, submerged victims or uncertainty about where to perform a search. There could also be an additional traumatic injury complicating the chances of survival. These factors could perhaps explain the relatively low survival rate (5.6%) in drowning cases where the SFARS was alerted and in which CPR was attempted by the EMS. There is not much evidence relating to the effects of fire and rescue services on survival from drowning. In fact, hardly anything has been published at all, other than rescues involving surf lifesaving organisations. (68, 121)

The organisation of surf rescue organisations or fire and rescue services or a mixture of both most probably differs widely around the world, from extensive national organisations with normative and strategic planning to local services based on voluntary staff in rural areas and LMIC.

In conclusion, trained rescue services could provide a professional secondary intervention if primary public, bystander rescue efforts fail or if the conditions require specialist equipment, such as boats, rescue-diving units or other means to make the drowning victim accessible to the EMS services.

## **5.10 What is the outcome after rescue diving?**

We found that survival from drowning was generally poor, 5.6% in Paper III. There were no statistically significant differences, but a trend towards higher survival in areas where there was a rescue-diving unit stationed in the rescue services organisation was nevertheless found. The data showed a 13% overall survival rate in individual cases after one month as compared to 4.7% in the non-diving group.

Although the data are non-significant ( $p=0.07$ ) and the study was perhaps underpowered due to a small cohort, our study shows that survival did not appear to be worse when using rescue-diving units. A trend towards higher survival was seen in drownings that took place in cold water and when the rescue team arrived early. The reason for this might be, in addition to the use of rescue-diving equipment, that rescue-diving units are better prepared for these types of accident and better trained in general water lifesaving skills. If more drowning victims were accessible for medical interventions, more patients would receive CPR and ALS and survival might increase.

An interesting intervention would be to introduce free diving on a large scale in SFARS services. A larger proportion of drowning victims could probably be accessed via pairwise free diving to reasonable depths, perhaps 0-6 metres, with a shorter delay than today. No survival was seen after more than 15 minutes of submersion in warm water in Paper III, a time limit within which only about half of the EMS and SFARS units have arrived at the scene. Fast-response free-diving units could arrive at an earlier stage, gaining access to submerged victims not easily accessible to bystanders at the scene of the accident. This should of course be followed by additional training, in alliance with the appropriate national jurisdiction and a high degree of personal safety.

SFARS rescue diving units should be aware of the limitations in their lifesaving potential caused by time delay seen. In warm water the response range for diving units and as well the whole of SFARS seems to be short. The actual driving time of the vehicle is probably limited to only a few minutes in order to rescue submerged survivors. If the delay in transportation only, exceeds 10 minutes there will most probably not be any intact survivors in warm summer waters. The SFARS statistical officers in each municipality should evaluate response range in relation to the findings in paper III and the chance of survival.

## **5.11 Does water temperature influence survival from drowning?**

Paper III showed no significant differences in survival related to water temperature. One interesting finding, however, was that there was no survival after more than 15 minutes' submersion in water warmer than 15 degrees Celsius and survival after up to 40 minutes' submersion in water temperatures of less than 15 degrees.

Most drownings occur in warm water during the summer and the delay will make it difficult for the SFARS and EMS to access the drowning victim in reasonable time. This is problematic with regard to the above-mentioned findings relating to survival in relation to submersion time, as Papers I and V showed that the EMS response time was the most important factor for survival.

Cold water thus appears to be neuroprotective in some cases, but we are still in need of large observational studies in humans, well powered and adjusted for confounders to address the relationship between water temperature and survival from OHCA due to drowning. We speculate that Paper III was underpowered adequately to address the research question of how water temperature influences survival from drowning.

## 6 CONCLUSION

Survival from OHCA due to drowning is low. A reduction in the EMS response time appears to have high priority, i.e. early ALS is important. The quality of CPR among surf lifeguards appears to be high and not affected by prior physical strain. In all treated OHCA cases, the majority were found at the surface and survival when rescue diving took place did not appear to be poorer than in non-rescue diving cases.

In a minor proportion of cases, cardiac disease could be a confounder for death due to drowning. Bystander CPR in OHCA due to drowning has increased over a 20-year period and the proportion of early survivors to hospital admission is increasing. We speculate that our studies were underpowered with regard to the opportunity adequately to assess the effects of bystander CPR on survival to hospital discharge.

A uniform Swedish definition of drowning based on the recommended international terms should be implemented throughout Swedish authorities and health care, in order to enhance the quality of data and improve the potential for future research.

## **7 FUTURE PERSPECTIVES AND IMPLICATIONS**

In overall terms, uniform prevention strategies and reporting are essential in order properly to evaluate the scope of the drowning problem on a national basis in the future. This would perhaps enable us to prevent drownings from happening and obtain more knowledge of this group in order to administer better interventions and provide more accurate research.

### **7.1 Community**

Parents should follow preventive advice, such as maintaining constant vigilance of their children in aquatic environments, using life jackets when boating, limiting access to bodies of water and learning the skills of basic life support, CPR. Bystanders should try to initiate early CPR and call for help at an early stage.

Alcohol is associated with drowning, a fact that should be taken into account when in and around water. Persons with medical disorders such as epilepsy or known heart disease should not swim or bathe alone.

If more drowning cases were witnessed, the delay to calling for help could be reduced, perhaps shortening EMS response times and increasing the rate of bystander CPR. If CPR were administered at an early stage with good quality, survival could perhaps be higher than it is today.

### **7.2 Pool lifeguards and surf lifeguards**

Lifeguards should maintain constant vigilance of bathers in the aquatic environment, with the opportunity to call for immediate help. Communities should evaluate the need of lifeguards at public pools and bathing areas.

Surf lifesaving organisations should evaluate the response time for surf rescue on the beach and structure patrolling services based on the delay to the start of IWR and CPR. Lifeguards should practise in-water resuscitation in both deep water with floating aids and in shallow water and should be aware of the difficulties involved in airway management in drowning victims. CPR and the use of an AED should be practised and the quality of CPR should be evaluated during training.

## 7.3 Ambulance services

Emergency Medical Service clinicians should be able to swim and perform easy rescues with floatation aids without endangering their own safety. They should also learn the skills of IWR in shallow water. The EMS clinicians should be aware of the potential neuroprotective effect of cold water seen in single cases of OHCA due to drowning. They should also be aware of difficulties associated with airway management in drowning victims.

Ambulance organisations should evaluate delay and try to shorten response times, as this appears to be the most important factor for survival in OHCA due to drowning, as shown in this thesis.

## 7.4 Police, fire and rescue services

Policemen and women should be able to swim and perform easy rescues with floatation aids without endangering their own safety. They should also learn the skills of IWR in shallow water and basic life support, CPR, with the use of an AED.

Fire and rescue staff should be able to swim and perform advanced rescues with professional rescue equipment without endangering their own safety. Fire and rescue staff should also learn the skills of IWR and basic life support, CPR, with the use of an AED. Individual rescue staff should be aware of the potential neuroprotective effect of cold water seen in single cases of OHCA due to drowning. The start of CPR could be initiated on a wider indication when CA is unwitnessed in cold water, perhaps exceeding 60 minutes of submersion.

Local fire and rescue services should focus on shortening the response times and time to access of the drowning victim. The Swedish Fire and Rescue Service should evaluate the opportunity to use rescue divers in advanced rescues and free-diving techniques to shallower depths in order to shorten the time to access the victim and to start of CPR. They should also be aware of the limitations caused by delay in relation to response/transportation time during summer as well as winter.

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## APPENDIX – Drowning CPR algorithm

# HLR VID DRUNKNING



Larma 112, starta livräddning om möjligt



### KOMMENTARER

#### 1. Inblåsningar på djupt vatten

Livräddning och inblåsningar på djupt vatten skall endast utföras om man är tränad till detta samt har tillgång till livräddningsutrustning såsom livboj, räddningstorp eller bräda!

- Öppna luftvägen, bedöm medvetande och andning
- Ge 10 inblåsningar, mun-till-mun eller mun-till-näs andning, "Lyft i hakan, blås i näsan"

#### 2. Inblåsningar på grunt vatten

- Ge 5 inblåsningar mun-till-mun så snart du bottnar
- Sätt ett knä under ryggen på den nödstälde om kroppen sjunker
- Förflytta personen upp på land/brygga
- Ett ökat motstånd vid inblåsningar är vanligt och rikliga mängder vätska kan komma upp

#### 3. HLR på land/brygga

- Placera personen plant
- Gör HLR 30:2 utan avbrott
- Torka bröstkorgen torr innan användande av hjärtstartare
- Personen behöver inte flyttas från ett fuktigt underlag i samband med användande av hjärtstartaren
- Fortsätt HLR tills personen blir vid medvetande, återfår normal andning eller tills ambulanspersonal tar över