Factors impacting on quality of prehospital advanced cardiac life support

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Short title – Quality of ACLS

Contents

Abbreviations

ACD-CPR = Active compression-decompression cardiopulmonary resuscitation

ACLS = Advanced Cardiac Life Support

AHA = American Heart Association

ALS = Advanced Life Support

CE = Conformité Européenne (European economic area conformity mark)

CI = Confidence Interval

CPC = Cerebral Performance Category

CPR = Cardiopulmonary resuscitation

CPR-PE = Cardiopulmonary resuscitation – Performance based Evaluation

ECG = Electrocardiography

ED = Emergency Department

EMS = Emergency Medical Services

ERC = European Resuscitation Council

IEMF = Institute for Experimental Medical Research

ITD = Impedance threshold device

NFR = No Flow Ratio

NFRadj = Adjusted No Flow Ratio

NFT = No Flow Time

OPC = Overall Performance Category

OUH = Oslo University Hospital

PCI = Percutaneous Coronary Intervention

PEA = Pulseless Electrical Activity

ROSC = Return Of Spontaneous Circulation

UUH = Ullevål University Hospital

VF = Ventricular Fibrillation

VT = pulseless Ventricular Tachycardia

Acknowledgements

List of papers

The thesis is based on the following papers:

Paper I   Olasveengen TM, Tomlinson AE, Wik L, Sunde K, Steen PA, Myklebust
               H, Kramer-Johansen J. A failed attempt to improve quality of out-of-
               hospital CPR through performance evaluation. Prehosp Emerg Care
               2007;11:427-33.

Paper II   Olasveengen TM, Wik L, Kramer-Johansen J, Sunde K, Pytte M, Steen
               PA. Is CPR quality improving? A retrospective study of out-of-hospital
               cardiac arrest. Resuscitation 2007;75:260-6.

Paper III   Olasveengen TM, Wik L, Steen PA. Quality of cardiopulmonary
               resuscitation before and during transport in out-of-hospital cardiac arrest.
               Resuscitation 2008;76:185-90.

Paper IV   Olasveengen TM, Vik E, Kuzovlev A, Sunde K. Effect of
               implementation of new resuscitation guidelines on quality of
               cardiopulmonary resuscitation and survival. Resuscitation 2009;80:407-
               11.

Introduction

Out-of-hospital cardiac arrest

Cardiac or circulatory arrest occurs when the heart becomes unable to generate blood flow. There is a wide range of etiologies, often categorized into cardiac or non-cardiac origins. Cardiac etiologies include the pure cardiac arrhythmias as well as acute and chronic coronary artery disease and chronic heart failure.[1-3] Most common non-cardiac etiologies include various respiratory failures, cerebrovascular disease, drug overdose and trauma.[1,4,5]

Heart rhythms during cardiac arrest are categorized into either shockable (ventricular fibrillation - VF or pulseless ventricular tachycardia - VT) or non-shockable (asystole or pulseless electrical activity - PEA). Although these rhythms are not directly diagnostic, ventricular fibrillation and pulseless ventricular tachycardia are strongly associated with cardiac etiologies.[6] The shockable rhythms may be treated successfully by timely defibrillation in an attempt to re-set the heart to a perfusing rhythm. Patients presenting with shockable rhythms are generally reported to have better outcome compared to those presenting with non-shockable rhythms,[7] but incidence has been gradually declining over the last decades.[5,8,9]

In a survey published in 2005 the incidence of out-of-hospital cardiac arrest in Europe was 38 per 100 000, with approximately 10% surviving to hospital discharge. The incidence of VF/VT arrest was 17 per 100 000, and most survivors in the whole material were in this subgroup with approximately 20% surviving to hospital discharge.[7]

Cardiopulmonary resuscitation (CPR)

The basic components of CPR consist of external chest compressions and artificial ventilation. Chest compressions most likely generate blood flow by a variable combination of intrathoracic pressure manipulation (thoracic pump) and direct compression of the heart (cardiac pump).[10] Basic ventilation strategies by lay persons provide gas exchange by utilizing expired air via mouth-to-mouth or mouth-to-mask,

while health care professionals usually ventilate with bag-valve mask and extra oxygen in the inspired gas.

Although CPR alone sometimes causes the heart to regain a perfusing heart rhythm, its main purpose is to delay tissue death by providing some circulation to the critical organs - heart and brain - until corrective treatments such as i.e. defibrillation may be administered. In a best case scenario CPR is thought to provide 30% of normal circulation to the heart and 60% of normal circulation to the brain.[10]

Components of pre-hospital advanced cardiac life support (ACLS)

Pre-hospital advanced cardiac life support builds on the basic components of external chest compressions and ventilation to include defibrillation, advanced airway management, drug delivery and circulation assisting devices.

Defibrillation (electric shocks applied through the chest wall to terminate VF or VT) is by far the most effective treatment among the components recommended in the ERC and AHA ACLS guidelines.[11,12] About 10-20% of defibrillation attempts will ultimately lead to a perfusion rhythm, but success rates rely heavily on the duration of cardiac arrest.[13-16] Chest compressions have been demonstrated to counteract some of the negative effects on shock success with time,[17] and recent clinical investigations[18,19] prompted changes in current ERC and AHA Guidelines recommending about 2 minutes of chest compressions prior to defibrillation in non-witnessed cardiac arrests.[11,12]

Airway strategies include more basic options such as bag-valve mask and oropharyngeal/nasopharyngeal airway and advanced options such as endotracheal intubation or various supraglottic airway devices. Both the ERC and AHA Guidelines recommend that the choice of airway reflect the level of rescuer competence and training to avoid unrecognized misplaced tubes and long pauses in chest compressions.[11,12]

Drugs used during ACLS are categorized into; vasopressors, antiarrythmics and other drugs and fluids. The preferred vasopressor is currently adrenaline administered intravenously every 3-5 minutes with vasopressin as an alternative. For refractory VF or VT cardiac arrest requiring > 3 shocks, intravenous amiodarone is the

recommended antiarrhythmic. Additionally, atropine is recommended for asystole or slow PEA (<60 per minute) as first presenting rhythm, and specific suspected causes of cardiac arrest such as i.e. pulmonary embolism, hypovolemia and hyperkalemia should be attempted reversed by administration of fibrinolytics, fluids and buffers, respectively. Despite current recommendations, there is little clinical evidence to support the use of any of these drugs during cardiac arrest. [11,12]

The most commonly used devises to assist circulation during cardiac arrest include active compression-decompression CPR (ACD-CPR), the impedance threshold device (ITD) and various mechanical chest compression devices. ACD-CPR is a hand held suction cup device to be mounted on the sternum in order to enable both active compression and active decompression. The AHA and ERC Guidelines currently states that ACD-CPR might be considered for in-hospital cardiac arrest, but out-of-hospital use is discouraged.[11,12] Still the device is used in certain EMS systems.[20] The ITD is a valve that limits airflow into the lungs between chest compressions and is designed to increase venous return to the heart during CPR. It is most often used together with an ACD-CPR device. There are two basic principles for the mechanical compression devices currently in use: mechanical piston devices, one of which includes an ACD-CPR suction cup, and a load distributing band with circumferential constriction. Current ERC and AHA guidelines suggest considering these devices in situations where manual compressions might be difficult (such as i.e. during transport).[11,12]

History of CPR and pre-hospital ACLS

These basic principles of chest compressions and artificial ventilation have been the cornerstone of modern CPR since the 1960s and have remained essentially unchanged since. CPR techniques as we know them today were developed by the collective efforts of Elam and Safar proving the usefulness of mouth-to-mouth ventilation with expired air[21] and Kouwenhoven, Jude and Knickerbocker who rediscovered the effectiveness of external chest compressions.[22] With the addition of closed chest defibrillation, modern CPR was complete.[23-25]

Modern pre-hospital advanced cardiac life support began with Pantridge's mobile coronary care unit in Belfast in 1966.[26] Concerned that most sudden cardiac deaths occurred before hospital treatments could be initiated,[27,28] he proposed that advanced physician led in-hospital treatments such as defibrillation and drug administration should be brought to the patient in order to reach those that might otherwise not survive to hospital admission. In his landmark publication he described six survivors among the ten patients who were resuscitated from out-of-hospital cardiac arrest.[26] The same year this was published, 1967, thus only a year after Belfast, an anesthesiologist-manned ambulance was also providing advanced care in Oslo, Norway.[29] Also in 1967 the Irish Heart Foundation sponsored training of the first non-medical ambulance personnel to use a defibrillator for pre-hospital cardiac arrest,[30] and other major cities were following suit.

As a cardiologist Pantridge had mainly been concerned with patients initially reporting chest pain. Lund and Skulberg in Oslo were anesthesiologists, and in parallel with Cobb and colleagues from Seattle they went further. In Oslo the anesthesiologist-manned vehicle responded to a wide range of medical emergencies, both medical and surgical. In Seattle they developed a two-tiered non-physician system that respond to the same wider range of medical emergencies. Fire-fighters trained in basic life support would respond to medical emergencies within few minutes followed by specially trained paramedics with more skills and equipment including defibrillators and drugs arriving as a second tiered response.[31] Paramedic programs were further developed during the 1970s in the Anglo-American emergency medical services (EMS) systems while the tradition of including physicians in pre-hospital care were maintained in many Franco-German EMS systems.[32,33] In Oslo the pre-hospital anesthesiologists rapidly moved into an additional role as paramedic trainers, while anesthesiologists in a rotor-wing air-ambulance service starting in Norway in 1978 had a more purely active physician role similar to the central European systems.

Current pre-hospital ACLS guidelines

Early defibrillation and chest compressions are the only pre-hospital interventions documented to actually increase survival to hospital discharge.[11,12] Other advanced options such as intravenous drug administration, [34,35] advanced airway management, [34,35] active compression-decompression[36] and use of mechanical devices[37] have yet to prove their positive impact on survival, but are still cautiously included in the current ERC and AHA ACLS guidelines.[11,12] The role of the physician in the pre-hospital arena is also under debate, and to date no randomized, controlled studies have been performed to evaluate effects of having a physician present during cardiac arrest. A recent review of physician involvement in pre-hospital emergency care concluded that there was limited evidence for increased survival for cardiac arrest patients treated by physicians in this setting.[38]

Some of the controversies that arise from uncertainties surrounding the effectiveness of advanced treatment modalities are: when should cardiac arrest patients be transported to hospital, when should resuscitation efforts cease, and who should be authorized to terminate the resuscitation efforts? Traditions vary greatly between physician-based Franco-German-type EMS systems and paramedic based Anglo-American-type EMS systems. Physician-based EMS systems tend to treat patients on site to a larger degree terminating the resuscitation effort out-of-hospital when regarded futile, while paramedic-based EMS systems in the US and UK often lack authority to cease resuscitation efforts leading to more cardiac arrest patients being admitted to hospital with ongoing CPR. The Scandinavian systems have taken a different route. While most ambulances are without physicians, paramedics are authorized to terminate resuscitation efforts without physician involvement. Survival rates for cardiac arrest patients receiving CPR in ambulances while en-route to emergency departments has typically been reported to be less than 1%,[39-41] and it has been speculated that this might partly be explained by inferior CPR quality during transport.[42-45] Performing CPR in a moving vehicle can also be hazardous to ambulance personnel and could be considered unethical,[46,47] especially if hospitals do not offer any additional effective treatments options for these patients.

Monitoring ACLS quality

With the evolution of defibrillators and monitoring equipment used in clinical practice comes new possibilities to register and collect data from cardiac arrest events. Earlier attempts to evaluate quality of ACLS were limited to having an investigators present on site[48] or examining audio recordings.[49] The first comprehensive evaluation of ACLS quality was done by Sunde et al using continuous ECG recordings to report chest compression rates and pauses in chest compressions from artefacts in the ECG signal.[16] A more detailed assessment of chest compression quality was documented using accelerometers mounted to the sternum during ACLS reporting chest wall displacement during compressions.[50,51] Transthoracic impedance is an alternative ACLS monitoring technique capable of measuring chest compressions, ventilations and blood movement through the chest.[52] Impedance is the measure of opposition to a sinusoidal alternating current, and may be measured across standard defibrillation pads on the chest wall. As air is a poor conductor of electric current, moving air into the lungs will be seen by the electrodes as increased impedance. This way impedance can be used to track ventilation. Chest compressions and blood movement also changes impedance, and impedance has therefore also been used to measure cardiac output. The capability to measure ACLS quality is now being incorporated into many defibrillators and stand-alone devices from different manufacturers, and the use of ACLS quality monitoring tools is expanding both for local quality improvement and in resuscitation research.

Importance of quality of pre-hospital ACLS

Quality of CPR has been shown to affect survival after cardiac arrest both in animal experiments[53-55] and in clinical studies of bystander CPR.[56-58] There are also indications that quality of ACLS is important for successful resuscitation, however all these studies are limited in their observational, often retrospective designs.[59-62] Length of experience among professional ACLS providers has been associated with improved outcome after cardiac arrest,[59] and defibrillation success was shown to increase with decreasing pre-shock pauses[60,62] and increasing compression depth.[62] Improved short-

term survival has also been demonstrated after improving CPR quality using automated feedback and structured post-event debriefing.[63] While improving quality of professional CPR has not been shown to improve survival to hospital discharge, it is still believed to affect outcome after cardiac arrest.

Recent clinical studies of ACLS quality both in- and out-of-hospital have shown substandard care with long pauses between too shallow chest compressions,[50,51] and frequent hyperventilation.[64,65] Emerging evidence of widespread substandard CPR resulted in major changes in the international 2005 CPR Guidelines,[11,12] with focus on good quality chest compressions and avoiding unnecessary interruptions. Removal of stacked shocks, immediate uninterrupted chest compressions following each shock and increasing the compression:ventilation ratio to 30:2 in non-intubated patients, were all changes made with intent to reduce pauses in chest compressions and improve vital organ perfusion.[11,12] Fewer pauses and better chest compression quality were hoped to improve overall survival after cardiac arrest.

Despite current advances in technology and increasing insight into the pathophysiologic mechanisms of cardiac arrest, survival remains dismal. Improving quality of pre-hospital care is believed to improve outcomes, and new strategies are needed to improve and develop better treatment options for patients suffering from out-of-hospital cardiac arrest.

Aims of the study

To evaluate the quality of cardiopulmonary resuscitation (CPR) and explore factors that impact upon CPR quality parameters. Specifically to evaluate:

1. Whether providing CPR performance evaluation would facilitate local education and implementation of CPR guidelines and, consequently, improve CPR quality in out-of-hospital cardiac arrest.

2. Quality of CPR performed by a physician-manned ambulance, and assess whether it changed with time influenced by developing scientific evidence and guideline changes.

3. Quality of CPR performed during transport after out-of-hospital cardiac arrest.

4. The effects of implementing the modified 2005 CPR Guidelines in the Oslo Emergency Medical System on quality of CPR and outcome after out-of-hospital cardiac arrest.

Materials and methods

Paper I

2.1. Study design and recruitment

The study was the third and last phase of a previously described research project[50,66] performed in three ambulance services: London (England), Stockholm (Sweden), and Akershus (Norway) and was approved by the respective regional ethics committees. Informed consent for inclusion in the study was waived as decided by these committees in accordance with paragraph 26 in the Helsinki Declaration.[67] In this prospective study registered at ClinicalTrials.gov (NCT00138996), patients older than 18 years suffering from out-of-hospital cardiac arrests of all causes who were treated by one of the modified defibrillators between October 2004 and June 2005 were included. Parallel to this study, as part of a separate study protocol and serving as a control group illustrating achievable CPR quality, identical equipment was used and data collected between January 2005 and April 2006 from the physician-manned ambulance in Oslo, Norway (manned by two paramedics and one anesthesiologist), all well informed about the results from the previous study documenting poor CPR quality and protocol adherence

2.2. Description of EMS systems.

All ambulances were staffed by paramedics. In Stockholm, a second tier unit also included a nurse anesthetist. Immediately prior to the study period, all involved personnel underwent an ACLS refresher course according to current international CPR guidelines[68,69] including use of the modified defibrillator. In Akershus, the local EMS algorithm required that patients with ventricular fibrillation or pulseless ventricular tachycardia received 3 minutes of CPR before the first direct current shock and between unsuccessful series of three direct current shocks.[18] The defibrillators were used in manual mode in Akershus and in semiautomatic mode in the other two regions.

2.3. Intervention.

Initiation of the study coincided with the publication of the results from the first phase of this research project at the European Resuscitation Council meeting in Budapest in September 2004, at which all head instructors and local coordinators from the respective sites attended. After the meeting, each ambulance service arranged meetings with the local CPR instructors where site-specific details on performance were presented and potential for improvements discussed by one or two of the head investigators. This CPR performance based evaluation (CPR-PE) was the only planned central intervention for the study, and it was our intention that the site specific information would increase knowledge and change current attitudes and training. Developing implementation strategies for local CPR quality improvement were left at the discretion of the local instructors, but included addition of the information into retraining and recertification of the crews that fall. Thus, all data were gathered 0–8 months after retraining with the new information. Because the strategies were expected to vary; the sites were also analyzed separately.

2.6. Equipment

Prototype defibrillators was based on standard Heartstart 4000 (Philips Medical Systems, Andover, MA, USA) fitted with an extra chest pad to be mounted on the lower part of the sternum with double adhesive tape. This chest pad was fitted with an accelerometer (ADXL202e, Analog Devices, Norwood, Mass), a force sensor (HBM DF2S-LAD from HBM, Darmstadt, Germany) and a pressure sensor (22PCCFBG6, Honeywell International Inc, Morristown, NJ). The defibrillators gave automated verbal and visual feedback on CPR performance. The Heartstart 4000 defibrillator was approved for investigational use in Europe (DNV; CE-mark; 2002-OSL-MDD-0009). Transthoracic impedance was measured by applying a near constant sinusoidal current across the standard defibrillation pads, and accelerometer and impedance signals were stored in an extra data card in the defibrillators.

2.5. Data collection and data processing

Data from each episode included scanned patient report forms and locally adapted Utstein style forms, as well as hospital records if relevant. ECG, accelerometer, and

transthoracic impedance signals, time and events were registered and collected from the defibrillator. Special attention was given to time without compressions or No Flow Time [NFT], No-flow ratio [NFR] defined as NFT divided by total time segment without spontaneous circulation, and chest compression depth. Adjusted no-flow ratio (NFRadj) is the fraction of no-flow time to time without spontaneous circulation but allowing for Guidelines recommended time for rhythm analysis, shock delivery, and pulse check if appropriate.[50]

2.7. Statistical analysis

Statistical calculations were performed by using a spreadsheet program (Excel 2002, Microsoft Corp, Redmond, WA, USA) or a statistical software package (SPSS 12.0, SPSS Inc., Chicago, IL, USA). Quality and outcome measures from this add-on-CPR-PE phase of the study were compared with the results from the second half of the second phase of the study, thus, cases with identical feedback as in the present add-on-phase. P-values for differences not equal to 0 were obtained from two-sided independent samples t-test, except for percentages of compressions with depth 38–51 mm, too deep, and too shallow before and after CPR-PE in which a Mann-Whitney U-test was used. Ten different quality variables were tested with no correction for possible alpha error included in the statistical analysis. A power analysis based on the results from the 39 episodes previously gathered revealed that to detect a meaningful reduction in NFR from 0.40± 0.16 to 0.30 with an alpha of 0.05 and a power of 0.8, we needed 43 cases in this study. Similarly, to detect a change in chest compression depth from 36 ± 7 mm to 40 mm, 65 subjects were needed.

Paper II-IV

2.1. Description of Oslo.

The city of Oslo covers 454 km2 and has a population of 548 617 (January 1st 2007) whereof 51% females and 4.4% over 80 years old. Oslo has had a continuous population growth the last twenty years, mainly due to migration leading to a larger proportion of young adults 20-39 and lower proportion of children and adults > 40

years compared to the rest of the country. Foreign immigrants now make up 24% of Oslo's population.[70]

2.2. Description of EMS and in-hospital treatment.

The city of Oslo has a one-tiered community run EMS system. On weekdays between 7:30 and 22:00, a physician-manned ambulance staffed by two paramedics and an anaesthesiologist functions on the same level as the regular paramedic staffed ambulances. The physician-manned ambulance is typically involved in ~35% of all cardiac arrests in our EMS, arriving as first responder to ~15-20%. All paramedics are trained to use the defibrillators in manual mode, re-starting chest compressions between manual analysis and shock delivery while defibrillator is charging. Endotracheal intubation was the standard method for securing the airways, followed by uninterrupted chest compressions with 10-12 interposed ventilations per minute.

In Oslo paramedics have full authority to discontinue CPR out-of-hospital without physician consult or transport to hospital. The decision to start transport to hospital with ongoing CPR is based on subjective case evaluation. There is no protocol guiding the decision, but a strong tradition for not transporting to hospital with ongoing CPR except hypothermic or intoxicated patients that could not be restarted out of hospital or the patient had a new arrest en route.

Nurses and paramedics staff the dispatch centre.

All hospitals in Oslo have goal directed post-resuscitation protocols including therapeutic hypothermia. The post-resuscitation protocols are applied to all patients regardless of initial rhythm or aetiology if active treatment is desired.[71] Prehospital 12 lead EKG is routinely sent to the cardiologist on call at OUH, Ullevaal after return of spontaneous circulation (ROSC). If coronary angiography and/or percutaneous coronary intervention (PCI) is indicated, patients are directly transported from the scene to one of the two hospitals with this capacity (24 hrs/day). OUH, Ullevaal receives approximately 60% of all cardiac arrested patients in Oslo.

2.3 The Norwegian Guidelines.

The Norwegian version of the 2005 ERC guidelines[11,72] was officially implemented in Norway in the winter of 2006. However, in the Oslo EMS, information, training,

certification and implementation was done in the autumn of 2005. Prior to this a modified version of the 2000 ERC guidelines[68] was followed in the Oslo EMS. In both versions the modification consisted of three instead of one (2000) or two (2005) minutes of CPR before and in between defibrillation attempts, based on results from a prior study published in 2003.[18] Stacked shocks were used prior to 2006. All other changes in the ERC 2005 CPR Guidelines were also followed in the modified Norwegian version.[11,72]

2.4. Study designs and recruitment

Data from all consecutive adult cardiac arrest patients treated by Oslo Emergency Medical Service (EMS) between May 2003 and April 2008 have been prospectively collected for a randomized study of the effect of intravenous access and drugs (the IV study, registered at clinicaltrials.gov NCT00121524).The studies described in papers II-IV were all retrospective, observational studies performed while the IV-study was ongoing, and the outcome from this trial unknown. Different sub-groups of patients were included for:

Paper II: Consecutive adult patients with non-traumatic out-of-hospital cardiac arrests of all causes treated by the physician-manned ambulance from May 2003 throughout 2006.

Paper III: Consecutive adult patients with non-traumatic out-of-hospital cardiac arrests of all causes who received CPR both before and during transport from May 2003 throughout 2006.

Paper IV: Consecutive adult cardiac arrest patients treated during a two year period before (May 2003-April 2005) and after (January 2006-December 2007) implementation of the new CPR Guidelines. A small proportion (16%) of the patients included in this study was also described in paper III.

2.5. Data collection

Utstein forms[73] are routinely filled out by ambulance personnel after every cardiac arrest and submitted to the study supervisor along with a copy of the ambulance run sheet. Automated, computer based time records from the dispatch centre supplement ambulance run sheets with regards to response times. For all admitted patients, additional hospital records were obtained from the respective receiving hospitals. Information from Utstein forms, ambulance run sheets, dispatch and hospital records are linked together with continuous ECG tracings as described below. Outcome categories were survival to hospital discharge with cerebral performance categories (CPC) 1-4 or non-survival (CPC 5).[73] CPC 1 and 2 were defined as favourable neurological outcome.

2.6. Equipment and data processing

Two different types of defibrillators were used in these studies:

a) Standard LIFEPAK 12 defibrillators (Physio-Control, a Division of Medtronic, Redmond, WA, USA) were used for most cases. ECGs with transthoracic impedance signals from LIFEPAK 12 were transferred to a local server at The National Competence Centre for Emergency Medicine (OUH,Ullevaal, Oslo, Norway). LIFEPAK 12 defibrillators routinely measure transthoracic impedance by applying a near constant sinusoidal current across the standard defibrillation pads. Data from each case were viewed and annotated CODE-STAT™ software (Physio-Control, Redmond, WA, USA). Ventilations and chest compressions were detected by changes in transthoracic impedance. Written information from the patient report forms and locally adapted Utstein style forms were compared with typical changes in CPR patterns as shown CODE-STAT™ 7.0.

b) From January 2005 to April 2006 a prototype defibrillator was used in nine cases. This prototype defibrillator was based on a standard Heartstart 4000 (Philips Medical Systems, Andover, MA, USA) and identical to that described above for paper I.

Time without spontaneous circulation, time without compressions during the time without spontaneous circulation (hands-off time; equivalent to no flow time in paper I), compression rate and the actual number of compressions and ventilations per minute were calculated for each episode. Hands-off ratio is defined as hands-off time divided by time without spontaneous circulation (equivalent to no flow ratio in paper 1). For the nine cases where the prototype defibrillator was used, data from the accelerometer were also included allowing compression depth analysis.

2.7. Statistical analysis

Statistical calculations were performed using a spreadsheet program (Excel 2002 and 2007, Microsoft Corp, Redmond, WA, USA) or a statistical software package (SPSS 12.0, 14.0 and 15.0 and Sample Power 2.0, SPSS Inc., Chicago, IL, USA). Normally distributed continuous variables are given as means with standard deviations. Non-normally distributed continuous variables are given as medians with interquartile range or 95% confidence intervals (CI). CIs for medians were calculated using normal approximation described by Altman[74] Comparisons of normally distributed continuous data was done with independent samples t-tests and non- normally distributed continuous data with Mann-Whitney U-tests, except for quality variables before and during transport that were analysed using two-tailed paired t-tests. Categorical outcome data were analysed using Chi-square tests with continuity correction. Multiple comparisons of continuous data were done with ANOVA and independent samples t-tests with Bonferroni corrections. P-values ≤ 0.05 were considered significant.

In paper III, sample size was powered to evaluate changes in CPR performance and not clinical outcome. Based on two-tailed paired samples t-test for CPR quality before and after transport, and assuming variable deterioration (approximately a 10% worsening in chest compression rate, for example), and power set at 0.8, minimum 25 cases would be needed to detect relevant changes in CPR quality.

In Paper IV, prognostic factors found to be significant in preliminary univariate and bivariate analyses were included in a multivariate logistic regression analysis together with implementation of modified 2005 Guidelines (dependent variable: discharged from hospital alive). The results from the multivariate logistic regression analysis were reported as adjusted odds ratios with 95% CI and p-values.

Summary of results

Paper I

Overall, information given on recent CPR performance quality in the EMS service did not have significant impacts on CPR quality performance compared to the previously published control phase.[66] Due to varying implementation strategies among the three sites and an uneven distribution of inclusions before and after the CPR performance evaluation, site specific analyses were done. Site A was shown to be superior to sites B and C, and showed some modest improvements in CPR quality after the CPR performance evaluation. At sites B and C there were no improvements in any of the measured CPR quality parameters.

Paper II

The physician-manned ambulance was dispatched as first responder to 21% of out-of-hospital cardiac arrests in Oslo. Quality of CPR as defined by hands-off ratios, compression depth, ventilation and compression rates gradually improved from 2003 to 2006, but were well within guideline recommendations throughout the study period. There was also a trend towards improved survival with 10% surviving to hospital discharge in the first two years (2003-2004) and 16% in the last two years (2005-2006), but this study was not powered to evaluate changes in outcome.

Paper III

Approximately 10% of out-of-hospital cardiac arrest cases received CPR during transport to hospital. The majority of these patients received manual compressions, while 9 patients were treated with a mechanical chest compression device. In patients receiving manual compressions, hands-off ratios increased from 19% on site to 27% during transport. There was no deterioration in CPR quality during transport for the patients who were treated with a mechanical device. Four patients (5%) survived to hospital discharge. Two survivors had received manual compressions during transport and survived with favourable neurological outcome, while the two survivors who had been treated with a mechanical device were discharged with CPC scores 3 and 4.

Paper IV

Quality of CPR improved after implementing modified 2005 ERC Guidelines. Hands-off ratio decreased from 23% to 14% and pre-shock pauses decreased from a median of 17 seconds to 5 seconds. Survival to hospital discharge increased from 11% to 13% after the change in guidelines, but this difference was not statistically significant. A logistic regression analysis was performed in an attempt to correct for any changes in registered patient characteristics with time. This analysis did not reveal any significant improvement in survival. A positive association with respect to survival to hospital discharge was found for young age, short response time, initial VF, ambulance witnessed arrest, coronary angiography and/or PCI and therapeutic hypothermia.

Discussion

This thesis addresses some of the issues that impact on the quality of advanced pre-hospital cardiac life support (ACLS) provided by ambulance personnel in Oslo, Akershus, Stockholm and London. Factors affecting ACLS quality could theoretically be classified into four categories: 1) Organization of EMS system, 2) Complexity of protocols (procedural demands for ACLS provider), 3) Skills and knowledge base of the ACLS provider and 4) Environmental factors (i.e. working in confined spaces or moving vehicles).

1) Organization of the EMS system:

EMS systems are organized in various ways based on both level of competence of rescuers and availability of one or more tiers of responders functioning on different levels. The organization of the EMS system is believed to be of importance for outcome in out-of-hospital cardiac arrest.[75,76] Most common EMS designs are one tiered systems consisting of ACLS trained paramedics or two tiered systems consisting of BLS trained first responders equipped with semiautomatic defibrillators and ACLS trained second responders. In many European countries the second, or sometimes third responder, includes a physician.[76,77] Two tiered response systems have been reported to have higher survival rates compared to one tiered systems, and these differences are often explained by shorter response intervals and shorter time to first defibrillation[75,76]

From Seattle it was reported 16 years ago that survival from cardiac arrest with a shockable rhythm declined by approximately 6-7 % for each minute delay in CPR and defibrillation.[78] While survival rates and thus the effects of time vary between health care systems, the rates consistently decrease with time before treatment in all reports. Approaches to shorten the EMS response intervals include measures to improve dispatch processing as well as shortening ambulance run times. EMS response intervals in the Oslo EMS system are reported to be 8-9 minutes, and have remained unchanged the past decade.[16] Having documented good quality in- and out-of-hospital care for cardiac arrest patients,[71] [Paper II and IV] shortening the interval between collapse and start of pre-hospital ACLS might currently be the most plausible way to further improve survival for out-of-hospital cardiac arrest in Oslo. Whether this might partly be achieved by increased dispatch efficiency and better ambulance logistics or require a large increase in EMS resources or more use of for instance police as first responders remains to be determined.

2) Complexity of protocols

Following widespread clinical reports of substandard ACLS both in- and out-of-hospital, [50,51,65,79] the treatment protocols in the 2000 AHA/ERC ACLS guidelines[68,69] were criticized for being too complicated and assuming unrealistic capabilities from the CPR-provider.[80] Major changes were made to the 2005 ERC and AHA guidelines

in an attempt to simplify protocols and improve quality of care.[11,12] The changes primarily intended to improve the quality of chest compressions by avoiding unnecessary interruptions, decreasing the number of defibrillations and increasing the compression:ventilation ratio to 30:2 in non-intubated patients. Fewer pauses and better chest compression quality was hoped to improve vital organ perfusion and thereby overall survival after cardiac arrest.[11,12]

Paper IV documented the effects of implementing the Norwegian modification[72] of the 2005 ERC guidelines[11] both on quality of ACLS and clinical outcome. The changes made to the treatment protocols were successful in reducing time without organ perfusion during ACLS, but this did not yield significantly increased survival. Nevertheless, it was demonstrated that implementation of new guidelines had been successful, and that it was possible to deliver quality of care in accordance with current ACLS guidelines. Although this was the first study to provide a comprehensive evaluation of actual pre-hospital ACLS quality before and after implementation of the new guidelines,[11,12] several other authors had demonstrated a positive impact of the guideline changes on clinical outcome.[61,81-83] Compared to these reports documenting improved survival after implementation of various modified 2005 Guidelines,[11,12] it was disappointing that we did not see a greater improvement in survival for our EMS system.

3) Skills and knowledge base of the ACLS provider

Papers I and II report ACLS quality on opposing ends of the scale, and illustrate the importance of education and training to ensure best possible quality of care for cardiac arrest patients. A human factors study performed by Odegaard et al. demonstrated that the ambulance personnel evaluated in Paper I were physically capable of consistently giving guideline-quality CPR even on a chest mimicking the stiffest chests found clinically, and concluded that there were non-physical barriers to guideline compliance.[84]

Having documented poor ACLS quality in initial investigations,[50,51] the effects of the real-time automated feedback intervention were disappointing.[66,85] Paper I described a strategy to improve the ACLS skills in these same sites by providing

performance based feedback. Simply presenting the performance evaluation to the CPR-instructors with emphasis on areas in need of improvement at the respective sites was clearly insufficient to improve their CPR quality. Leaving the sole responsibility of developing an implementation strategy to the respective CPR instructors gave little control over how the information was used. A recent example from Finland illustrated regional differences in implementation of guidelines between two university hospital districts despite similar EMS education levels and structure. Local attitudes and policies were believed to have been greater barriers at one site, and the authors stressed the importance of local implementation strategies and follow-up.[86] Evidence-based medicine is increasingly emphasized, but much less attention is given to evidence based implementation.

The results from paper II indicated that high quality ACLS can be achieved in the out-of-hospital setting with a specialized ambulance team consisting of experienced paramedics and anesthesiologists believed to be highly skilled and knowledgeable. Previous studies have reported that physicians are more efficient in managing procedures such as ECG analysis and endotracheal intubation,[49,87] and are more likely to comply with treatment guidelines than other ambulance personnel.[86] The role of a physician in the pre-hospital arena is under debate, and to date no randomized, controlled studies have been performed to evaluate effects of having a physician present during cardiac arrest.

A recent study compared the quality of ACLS and outcome for patients treated with and without involvement from the physician manned ambulance within the Oslo EMS. Although ACLS performance was superior in the physician manned ambulance, there were no significant improvements in clinical outcome.[88] The study design was limited to evaluating effects of physician presence on-site on quality of care and outcome for cardiac arrest patients, not of overall effects of having motivated physicians involved in pre-hospital care. It is possible that the most valuable effect of pre-hospital physicians is providing up-to-date knowledge, good quality training and motivation to improve quality of care in an entire EMS system. Having a defined "team-leader" presumably adds significant knowledge and enthusiasm to the team, and this has been

shown to be an important factor when improving quality in other areas of clinical medicine.[89]

Several studies have attempted to evaluate the effect of physicians in pre-hospital emergency care by comparing different systems rather than the effect of the physicians' presence on scene within one system.[36,90,91] These comparisons are difficult to interpret as there might be other differences between systems in a variety of factors such as; population demographics, response intervals, organization, training methods, and in- and out-of-hospital treatment protocols.

4) Environmental factors

Pre-hospital ACLS is often performed under suboptimal working conditions such as confined spaces, harsh weather conditions, in public places or private homes under the constant scrutiny of bystanders in various emotional states. Although good training and field experience might help ALCS providers handle these challenges professionally, these factors are still expected to impede ACLS. Care must be taken to ensure the safety of both patients and ACLS providers by avoiding hazardous working conditions whenever possible.

Paper II was the first clinical study to documenting the effects of the added environmental challenges in performing ACLS during transport to hospital. It was clearly demonstrated that chest compression quality deteriorated during transport to hospital. This deterioration in quality was in agreement with previously published manikin data.[42-44] As procedures such as intubation and establishing intravenous access were performed before transport, the increased fraction of time without chest compressions during transport is most likely caused by difficult working conditions in a moving vehicle.

The prognosis for cardiac arrest patients without spontaneous circulation on arrival to hospital has earlier been shown to be extremely poor,[39-41] which has supported current recommendations to treat and stabilise patients on scene or terminate the effort out-of-hospital when feasible.[11,12] Although the number of patients in the present study is limited, it was unexpected to find the relatively high survival rate (5%). Transport to hospital with ongoing ACLS is less common in Norway compared to other countries

where ambulance personnel do not have the authorization to terminate resuscitation efforts in the field.[75,92] Creating these hazardous working conditions are not only ethically questionable with regard to patient and rescuer safety,[46,47] it also adds considerably to the challenge of performing adequate ACLS and should be avoided whenever possible. Larger materials are needed to gain insight into which patients should be selected for transport to hospital with ongoing CPR.

The association between ACLS quality and increased survival after cardiac arrest is elusive and has yet to be sufficiently documented clinically. The Oslo EMS has had continuous focus on the importance of chest compression quality since the late 1990s[16], and the clinical importance of reducing the hands-off-ratio from good (23% in 2003-05) to even better (14% in 2006-07) could be discussed. Shortening pre-shock pauses,[60,62] compressing with adequate depth[62,66] and at an adequate compression rate[93] have only been shown to be associated with improved short term survival. It is challenging to obtain a sufficient number of cases to demonstrate significant improvements in survival in a patient group where overall survival remains low. There is also the complicating fact that patients who are easily resuscitated within few minutes will survive despite seemingly "poor quality CPR" with few chest compressions.

With increased focus on the importance of documenting CPR quality in resuscitation research,[94] it seems likely that a better understanding of the association between the CPR quality parameters and survival to hospital discharge will become clearer as new evidence emerges.[95]

Conclusions

The main conclusions of these studies are:

1. Quality of CPR did not improve by providing CPR performance evaluation alone. Bringing about changes in established practice likely requires a well thought through implementation plan, addressing current barriers and giving sufficient time for repeated performance evaluations documenting progress. More research is needed to give evidence-based implementation strategies.

2. High quality CPR in accordance with guideline recommendations is achievable in the out-of-hospital setting.

3. Quality of CPR during out-of-hospital cardiac arrest deteriorates during transport. More information is needed to determine which patients benefit from transport to hospital with ongoing CPR.

4. Quality of CPR improved after implementation of the modified 2005 Guidelines with reduction in both pre-shock pauses and total time without chest compressions, but these improvements did not yield significant increase in survival.

Future perspectives

Development of comprehensive cardiac arrest registries and new technologies for CPR quality assessment has allowed us to evaluate current quality of care for out-of-hospital cardiac arrest patients and monitor effects of changes made to protocols or training strategies. Significant challenges remain in developing implementation strategies which may be widely applied to narrow the gap between guidelines and practice. Better tools are needed to develop and formally evaluate pre-hospital quality of care strategies in an effort to both improve outcome and secure the best possible utilization of limited pre-hospital resources.

Errata

Paper II: The use of ANOVA with post hoc Bonferroni corrections to evaluate changes from 2003 to 2006 could have been replaced with linear-by-linear association for categorical variables taking into account the temporal evolution with time instead of considering the time periods as independent groups.
Paper IV: The title of table 2 should read "Quality of CPR from May 2003 to December 2007".

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