Searching for factors contributing to substandard quality of cardiopulmonary resuscitation in out-of-hospital cardiac arrest

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List of abbreviations

A-CPR	Advanced CPR; CPR including drug administration, endotracheal intubation and defibrillation.
AED	Automatic external defibrillator; an externally applied defibrillator with software that calculates whether shock is indicated automatically
ALS	Advanced Life Support; A-CPR
B-CPR	Bystander CPR
BLS	Basic Life Support; CPR with chest compressions and ventilations
CI	Confidence Interval; an interval indicating the reliability and precision of an estimate. A 95% CI of a mean represent an interval which includes the true value in 95% of the cases.
CPR	Cardiopulmonary resuscitation
EMS	Emergency Medical System; various organisation, but usually consist of a call centre with a dispatch unit and several first-responder units and ambulances.
PEA	Pulseless Electrical Activity
ROSC	Return of Spontaneous Circulation
VAM	Voice Advisory Manikin; a manikin used in experimental settings and training that measures and gives automated feedback on the performance via an attached computer

List of papers

The thesis and included original papers are based upon research at the Institute for Experimental Medical Research at the University of Oslo and Ullevål University Hospital (after January 1 2009, Oslo University Hospital, Ullevål)

1. Ødegaard S, Sæther E, Steen PA, Wik L. Quality of lay person CPR performance with compression-ventilation ratios 15:2, 30:2 or continuous chest compressions without ventilation on manikins. Resuscitation 2006;71(3):335-340

2. Ødegaard S, Pillgram M, Berg NEV, Olasveengen T, Kramer-Johansen J. Time used for ventilation in two-rescuer CPR with a bag-valve-mask device during out-of-hospital cardiac arrest. Resuscitation. 2008;77:57-62

3. Ødegaard S, Kramer-Johansen J, Bromley A, Myklebust H, Nysæther J, Wik L, Steen PA. Chest compressions by ambulance personnel on chests with variable stiffness: Abilities and attitudes. Resuscitation. 2007;74:127-134.

4. Ødegaard S, Olasveengen T, Steen PA, Kramer-Johansen J. The effect of transport on quality of cardiopulmonary resuscitation in out-of-hospital cardiac arrest. Resuscitation 2009 (in press, doi:10.1016/j.resuscitation.2009.03.032)

Introduction

The science of resuscitation had its vague beginning with description of external chest compressions in the mid 19th century [1, 2], but was not recognized properly until 1960. That year Kouwenhoven, Jude and Knickerbocker "re-invented" external chest compressions [3]. Safar, Jude, Kouwenhoven and Hackett published the combination of chest compressions and artificial mouth-to-mouth ventilation, the birth of modern CPR, in landmark articles the following years [4, 5].

In parallel external electric defibrillation had its birth, a product and process perfected by Lown et al [6, 7] and Zoll et al [8]. Pantridge and Geddes placed a defibrillator in a mobile unit in Belfast in 1966 and were the first to give cardiac arrest patients advanced care outside of hospital [9]. Oslo followed June 15 the year after. Since then the interest, knowledge and resources within this area of medicine has expanded greatly.

The first standards for resuscitation were published by the National Academy of Sciences-National Research Council and American Heart Association (AHA) in 1974 [10] based on techniques presented in the previous mentioned landmark articles [4, 5]. Since these first Standards were published, there have been updates on a regular basis [11-15]. The first two updates in 1980 and 1986 [11, 12] were called "Standards and Guidelines", from 1992 only "Guidelines" was used [13-15]. This change had the specific purpose "to facilitate the introduction of innovations based on new data and to protect the physicians' prerogative for discretionary action, particularly since the term *standards* has important legal as well as medical connotations" [13].

In the beginning of the 1990ies other organisations with interest in resuscitation science were established around the world. The guidelines process has thereafter evolved into a large, international collaboration under the auspices of International Liaison Committee of Resuscitation (*ILCOR*), with ILCOR publications [16-19] and ILCOR based publications more specifically suited for the US [14, 15], Europe [20, 21], Australia [22] etc down to national guidelines approved by appropriate international bodies [23].

The guidelines revision process has the overall aim of improving survival and outcome of cardiac arrest patients through new recommendations based on comprehensive evaluation and assessment of all available knowledge at that time [24]. Even though the guidelines might vary slightly in different parts of the world, the differences are small and should always be based on scientific evidence.

Cardiac arrest takes place in- and out-of-hospital. The two scenarios differ greatly in setting, response time, medical and diagnostic equipment and above all in patient population [25, 26]. The incidence of and outcome after out-of-hospital cardiac arrest treated by emergency medical service (EMS) systems has been recently reviewed. In the US overall incidence was 55 per 100 000 person-years, and 21.3 per 100 000 person-years for ventricular fibrillation (VF) sudden cardiac arrests with survival rates to hospital discharge of 8.4% and 17.7%, respectively in peer-reviewed articles published between 1980 and 2003 [27]. A similar study from Europe reported overall incidence of 37.7 and 16.8, for VF, both per 100 000 person-years, with survival rates of 10.7% and 21.2% respectively [28]. There is great variability in reported outcome. Rea et al reported survival to hospital discharge for EMS systems organising resuscitation services in the range 1.8-21.8% in the US [27] and 3.6-30.7% in Europe [28]. In another recent review [29] the range was 2% to 49% for bystander-witnessed arrests of cardiac etiology discharged alive.

In later years a marked decline in incidence of treated out-of-hospital cardiac arrest has been observed, especially for cases with initial rhythm VF [30- 32]. Cobb et al [30] speculate that this might reflect the general reduction in age-adjusted mortality attributed to coronary heart disease [33, 34].

VF is characterised by a chaotic, irregular waveform on the ECG and results in a quivering heart unable to pump blood. With time the ECG waveform loses amplitude, culminating in complete loss of cardiac electrical activity: asystole [35]. The chance of finding a patient with VF as initial recorded rhythm thus decreases with time [36]. The third subclass of cardiac arrest rhythms: pulseless electrical activity (PEA) as initial rhythm often reflects a non-cardiac etiology [37-39].

In 1984 Roth listed VF or pulseless ventricular tachycardia (VT) present at EMS arrival, short EMS response time and bystander CPR as important positive prognostic factors for survival after out-of-hospital cardiac arrest (OOH CA) [40]. These and other factors associated with outcome have since been relatively consistently reported in numerous studies [41-54].

Larsen et al presented a graphic model for predicting survival after OOH CA with VF as first presenting rhythm based on time to CPR (chest compressions and ventilation), time to defibrillation and time to advanced life support with drugs and airway devices (ALS) [53]. Herlitz et al [45] reported six factors associated with survival in OOH-cardiac arrest cases which were not crew witnessed and where CPR was attempted: initial rhythm, delay to arrival of EMS, place of arrest, witnessed status, bystander CPR and age. Time from arrest until initiation of CPR, until defibrillation in cases of VF and initial rhythm shockable or non-shockable have been the factors most consistently found to influence outcome [41, 43-45, 47, 50-52, 54]. Place of arrest and witness status are both factors influencing these factors, while the influence of age has been more inconsistent in the literature [27, 28, 42, 55- 57]. It is important to note that these factors cannot all be used as independent in multifactorial analysis of cardiac arrest materials. As described above VF will gradually deteriorate to asystole with time, thus initial rhythm varies with delay to arrival of EMS. There is similar co-variation for place of arrest, witness status and bystander CPR [58]. Many studies fail in taking this into account.

Patients found in non-shockable rhythm have much poorer outcome than those found with shockable rhythm, usually by a factor of 5-10 [27, 28, 59, 60]. Also for patients with non-shockable rhythm decreasing age, witnessed arrest, bystander CPR, cardiac arrest outside home, shorter ambulance response time and need for defibrillatory shock have been associated with increased survival [60].

The approach for non-shockable rhythms is to initiate CPR with the purpose of conversion to a shockable rhythm both if it is initial rhythm and if it occurs later in the resuscitation effort [15, 21]. This is recently debated in several articles, initiated by Hallstrom et al who reported that patients with initial non-shockable rhythm did not appear to survive if they received defibrillation attempts [61]. They suggested a different approach in these patients with emphasis on high-quality CPR with minimum of interruptions, appropriate ventilation and treatment of reversible causes before defibrillation is considered. Subsequent publications from Sweden, Japan and Norway come to the opposite conclusion. All found that patients with initial non-shockable rhythm with conversion to VF and defibrillation attempts tended to have higher survival rates [60, 62, 63].

Cardiac arrest in adults is often caused by underlying coronary artery disease and myocardial ischemia and typically presents as sudden and unexpected. Although the incidence appears to be decreasing [30-32, 64], the incidence of VF as initial rhythms is still high [30, 64, 65] and rapid defibrillation has maintained focus [21]. Shock delivery promptly after recognition of VF is pivotal for successful defibrillation [21] and is supported by observations of higher rates of ROSC and survival to hospital discharge after implementation of programs for early defibrillation by first responders [56, 66-70] and lay rescuers in public venues [69, 71]. Harve et al [72] recently reported that untrained lay persons were able to use a defibrillator with dispatcher assistance without compromising the performance of CPR.

The optimal timing for electrical defibrillation is recently more debated in resuscitation fora, based on data suggesting that prompt defibrillation loses its efficiency when attempted after prolonged intervals of VF [73, 74]. Weisfeldt and Becker thus introduced a three phases model of cardiac arrest; each with its physiological characteristics and optimal initial therapy [75]. They suggested that during the first four minutes the patient is in an "electrical phase" where immediate defibrillation attempt is the most efficient treatment. During the following "circulatory phase" from 4 to approximately 10 minutes after collapse, the myocardium is in a state where ROSC is less likely to occur unless the situation can be improved by a period of CPR. A final "metabolic phase" is assumed reached after about 10 minutes, when according to Weisfeldt and Becker in 2002, no current therapies appear to improve chance of survival and good outcome [75].

The electrical/circulatory phase part of the hypothesis is supported by studies from Seattle and Oslo documenting increased survival when defibrillation was deliberately delayed in order to give CPR by the EMS first regardless of whether bystander CPR had been given if EMS response time was more than 4-5 minutes with historic controls in Seattle [74] and randomized in Oslo [76]. For shorter response times there was no improvement in outcome with CPR first in either study [74, 76]. These findings have been supported a recent experimental animal model [77]. However, these studies have been challenged by a randomised study from Australia -05 where delaying shock to give 90 s of CPR did not improve survival [78]. It is tempting to speculate that this inconsistency could be due to differences in quality of CPR as the Australian study report ROSC rates of only 9 % for CPR first and 8 % with immediate defibrillation and survival rates of 4 % and 5 %, respectively. These numbers are much lower than normally expected for the arrest factors reported known to influence outcome as described above. Seattle with positive effect of EMS CPR on the other hand has consistently reported excellent results for out-of-hospital cardiac arrest [27], and Oslo reports much higher overall survival than the Australian study for relatively similar arrest factors [79] and has recently reported good quality EMS CPR [80].

Recent developments have made it possible to evaluate quality of professional CPR via defibrillators. In short chest compressions can be evaluated with accelerometers and force transducers attached to the sternum and via changes in the ECG. ECG electrodes and defibrillator pads can in addition monitor ventilations and compressions as trans-thoracic impedance (resistance against an alternating current routinely sent by the defibrillator) varies with the amount of air in the lungs [26, 81-83].

Studies have found quality of CPR far from guideline recommendations in various countries and both in- and out-of-hospital [25, 26, 84-86]. There has been a tendency to many, too long pauses in chest compressions that are too shallow [25, 26, 85]. Edelson et al [87] found both shorter pre-shock pauses and higher mean compression depth during the 30 seconds preceding the pre-shock pause to be associated with successful defibrillation. ECG analysis also indicates decreased likelihood of ROSC with increased pauses in chest compressions [88], and increased likelihood with good quality CPR [89].

Animal data also indicate that ventricular fibrillation waveform [90] and outcome after prolonged untreated ventricular fibrillation might improve with chest compressions before defibrillation attempts, and that early and repetitive shocks should be avoided [91]. In another recent study in swine with prolonged VF ROSC and survival were equivalent for 90 s, 180 s and 300 s of CPR before shock [92].

For bystander CPR prior to defibrillation, data are also inconsistent. Vilke et al reported improved survival for time since collapse > 4 minutes, but not for < 4 minutes [93]. In a large Swedish study totaling 10 966 cases, on the other hand, bystander CPR improved survival also for the shortest 3-4 minute time interval from cardiac arrest to defibrillation [58]. Neither study is inconsistent with the three-phase model as shock was not delayed in order to give CPR. More confusing is the study from Rochester, Minnesota where bystander CPR failed to improve survival for any call-to-shock times <5, 5-8 and >8 minutes, only a higher frequency of ROSC with defibrillation and a trend toward increased neurologically intact survival with bystander CPR for > 8 minutes [94]. The study only included 218 patient and the results must therefore be interpreted with caution.

Despite much emphasis on training both professional responders and the general public in CPR [15, 21, 95, 96], knowledge and skills attained appear to rapidly deteriorate [97, 98]. The frequency of bystander initiated CPR varies greatly between 28% in some US studies to approximately 50 % in Seattle and in Norway [76, 99, 100]. So in addition to rapid deterioration in competence after CPR-courses, bystanders' willingness to perform CPR in real life scenarios is also an issue.

Studies have indicated that lay people are less likely to perform CPR if this includes mouth to mouth ventilations than for chest compressions only [101, 102]. According to Taniguchi et al lay people in Japan were mostly afraid that they wouldn't be able to perform correctly, while health care providers feared contracting a disease [102]. In a study by Swor et al bystanders stated that panic, perception that they would not be able to do CPR correctly and fear of hurting the patient were their principal reasons for not performing CPR, not factors such as fear of infectious diseases [103].

Not surprising, in addition to whether bystanders perform CPR or not, the quality of their effort is important. Pantridge and Adgey [104] reported already in 1969 that efficient CPR provided within 4 minutes after collapse in patients with VF resulted in a survival rate of 93% as compared to 61% in the non-efficient group. In the early 90ies groups from Belgium, Norway and the US all reported approximately four-fold increase in survival to hospital discharge for good quality CPR vs. poor quality or no bystander CPR [46, 105, 106]. Good CPR was defined as palpable carotid or femoral pulse and intermittent chest expansion with inflation attempts. A recent Swedish study supports these findings with 2.2% 1-month survival with no bystander CPR, 4.9% with CPR from lay rescuers and 9.2% with bystander CPR from professionals. Odds ratios were 2.04 (95% CI: 1.72 – 2.42) for lay bystander CPR versus no bystander CPR and 1.37 (95% CI: 1.12-1.67) for lay bystanders versus healthcare providers [107].

In summary we have information suggesting that quality of CPR is important both in professional and bystander CPR. Based on already existing techniques for quality measurements and audiovisual feedback, systems for automated on-line feedback on CPR quality during manikin training were developed [108]. As some defibrillators also had the capacity to monitor CPR quality as described above [26], the same feedback techniques were integrated in modified defibrillators and tested clinically [83], [109]. When CPR was not in accordance to 2000 Guidelines [14, 20] automated verbal and visual prompts were given to the rescuer. It was hoped that real time continuous feedback would help ambulance personnel correct their performance. Quality improved some, but was still poor and far beneath Guidelines recommendations. Mean time without chest compressions improved from 48% to 44% when feedback was added and mean chest compression depth from 34 mm to 38 mm in the European out-of-hospital arrest study [83]. Also in-hospital in the US feedback only modestly improved quality of CPR [109].

In the European study mean time without chest compressions decreased from 61% before to 41% after intubation; a 20% absolute reduction. This might indicate that pauses for ventilation contribute to the high percentage of time without chest compressions [110].

Both quality and quantity of CPR decreases with increasing numbers of procedures and complexity [111]. Sternbach et al recommended already in -84 a simplification of basic life support training curricula to enable better learning and retention of skills [112]. This was also reflected in the most recent 2005 Guidelines for resuscitation, where simplification was emphasized [21].

The 2005 Guidelines changed the compression:ventilation ratio from 15:2 to 30:2 with emphasis on chest compression depth and minimal time without chest compressions [15, 21]. The change in compression:ventilation ratio was due to several factors. Blood flow falls abruptly with chest compression pauses and it takes a few compressions to rebuild a perfusion pressure in pigs [113], and another pig study suggested that 30:2 could be the ratio providing the most efficient oxygen transport to tissues when optimal CPR was performed [114]. Babbs et al [115] calculated theoretically that a compression:ventilation ratio of 30-70:2 gave the most optimal oxygen transport.

Kern et al reported good neurologic recovery with continuous compressions without ventilation in pigs [116], and in a randomized study of dispatcher assisted CPR from Seattle outcome was no worse for compressions only CPR than 2000 standard 15:2 compression:ventilation ratio [100]. It has therefore been suggested to omit ventilation from bystander CPR [24].

While an increased compression:ventilation ratio or chest compressions only should increase the number of compressions per minute, the quality of the chest compressions might be reduced if longer series cause more rescuer fatigue. Fatigue has been reported to be a problem during continuous chest compressions performed by professionals [117-119].

Some patients are transported to hospital with ongoing CPR or the team performs CPR on scene until ROSC or the resuscitation effort is terminated, and protocols guiding these decisions vary between EMS services. Policy might vary with distance to hospital, environmental factors like family presence, local tradition or that non-physicians are not allowed to declare a patient dead without confirmation by a doctor. Quality of CPR has been found to be of poorer during transport than for CPR performed on scene in manikin studies [120-122].

Aims of the study

To survey possibilities for improvement of CPR quality among both lay rescuers and professionals. Specifically:

1) How is quality of CPR performed by lay rescuers with compression:ventilation ratios 15:2, 30:2 and chest compression only in manikins? Are they capable of performing CPR with an increased number of chest compressions per minute without deterioration of quality?

2) Are professional rescuers capable of delivering two rescue breaths within the 4-6 seconds recommended in the Guidelines in real patients, or are pauses used for ventilations a major contributing factor to the high percentage of time without chest compressions found in several studies?

3) Why do professionals perform substandard CPR when real-time feedback is provided? Are they not physically capable of performing to Guidelines recommendations or might there be psychological factors that prevent them from doing good quality CPR?

4) How is quality of CPR during patient transport to hospital? How is quality prior to initiation of transport in episodes with later transport with ongoing CPR compared to quality of CPR in episodes without transport during ongoing CPR?

Materials and methods

Paper 1

Quality of lay person CPR performance with compression-ventilation ratios 15:2, 30:2 or continuous chest compressions without ventilations on manikins

Study subjects were 68 non-paid volunteers recruited among travelers at Oslo International Airport, and among clients at a community day centre for elderly.

Each was randomized to 15:2, 30:2 or continuous compressions without ventilations, and instructed to give one-rescuer CPR in the chosen pattern with no further instruction on how to perform CPR. The sessions were aimed to last five minutes.

The manikin system was a Skillmeter Resusci Anne (Laerdal Medical, Stavanger, Norway) connected to a laptop computer. The Skillmeter screen was only visible to the researchers, and no feedback was given to the study subjects during the five minutes period. CPR performance on the manikin was transmitted to the computer, and the Skillmeter software (PC Skillmeter, Laerdal Medical, Stavanger, Norway) stored information on timing, ventilation flow rates and volumes, and the movement of the sternum with chest compression and release.

The variables to be evaluated were ventilations per minute, tidal volume, time spent on two ventilation attempts, compression depth, compression rate, time without chest compressions and number of compressions per minute.

Paper 2

Time used for ventilation in two-rescuer CPR with bag-valve-mask device during out-of-hospital cardiac arrest

All non-traumatic out-of-hospital cardiac arrest patients over 18 years of age from London,

Stockholm, Akershus and Oslo ambulance services that were treated with study defibrillators were included between March 2002 and December 2005.

Six prototype defibrillators were deployed at each site based on a standard Heartstart 4000 biphasic defibrillator with an accelerometer and a pressure sensor enabling measurement of chest compression rate and depth. Transthoracic impedance was used to detect ventilations. Transthoracic impedance was used to detect both compressions and ventilations from the data obtained from the LIFEPAK 12 used in Oslo.

Automated feedback on quality of CPR was provided from October 2003 to June 2005 in the ambulance services of London, Stockholm and Akershus.

All ambulances were staffed with paramedics trained and tested in the use of the employed defibrillators, as well as annual ALS certification according to the 2000 international guidelines [21].

ALS included bag-valve-mask ventilation and chest compressions in a 15:2 ratio until endotracheal intubation, which was part of all local protocols. Time of intubation was recorded on the patient report forms, and the exact time was identified by reviewing characteristic changes in compression:ventilation pattern in the ECGs with transthoracic impedance signals.

Each episode was manually reviewed. Pauses in chest compressions before intubation were analysed and classified according to activity; pauses for two ventilations, pauses for two ventilations and an intervention, pauses with a different number of ventilations, and pauses without ventilations.

Primary outcome was time needed to perform two ventilations with a bag-valve-mask device.

Paper 3

Chest compressions by ambulance personnel on chests with variable stiffness: Abilities and attitudes

Study subjects were 80 volunteers recruited in connection with ALS retraining sessions for ambulance personnel in Akershus and London. The manikins were four modified Skillmeter Resusci Anne manikins linked to computers to enable processing and calculation of the data and computer-assisted feedback. In addition to the feedback system the modification consisted of built-in thoracic springs of variable progressive stiffness and a damping mechanism. These manikins will in the following be termed Manikin 1—4 with 4 as the stiffest.

CPR performance data were collected including data on chest compression rate, depth, number of chest compressions per minute and time without chest compressions.

The study subjects all filled out a sheet for demographic data and were then asked to form pairs. The pairs performed 5 min of CPR on each of the manikins in a randomised sequence. The old Guidelines with a 15:2 ratio were chosen to enable comparison of data with our clinical study of CPR quality with defibrillator feedback on CPR in 2003—2004. The study subjects were given short breaks between the four sessions and were allowed to change roles during the five-minute sessions. The variables to be measured were compression depth, compression rate, actual number of compressions per minute, and time without chest compressions as percentage of the total time without spontaneous circulation (no flow ratio), ventilation attempts per minute, and time spent on two ventilation attempts.

After finishing all four sessions they were given a questionnaire with statements relating to different aspects of CPR which they should score from totally agree to totally disagree.

Paper 4

The effect of transport on quality of cardiopulmonary resuscitation

All non-traumatic out-of-hospital cardiac arrest patients over 18 years of age from London, Stockholm and Akershus ambulance services who were treated with study defibrillators and had data from both before and during transport to hospital with ongoing CPR between March 2002 and June 2005 were included.

Six prototype defibrillators were deployed at each site. These investigational devices were based on a standard Heartstart 4000 biphasic defibrillator with addition of an extra chest sensor designed for placement on the lower part of the sternum with double adhesive tape. This chest pad was fitted with an accelerometer enabling measurements of chest compression rate and depth. Trans-thoracic impedance was used to detect ventilations. Automated feedback on quality of CPR was provided from October 2003 to June 2005 in the three ambulance services.

All ambulances were staffed with paramedics trained and tested in the use of the employed defibrillators, as well as annual ALS certification according to the 2000 international guidelines [21]. ALS included bag-valve-mask ventilation and chest compressions in a 15:2 ratio until endotracheal intubation, with continuous chest compressions and interposed ventilations thereafter as per all local protocols. There was no protocol for when to transport patients to hospital with ongoing CPR, so this was decided by the responders in each single case.

Each episode was manually reviewed and the episodes were divided into "before transport" and "during transport" for separate analysis. Information on transport was taken from the ambulance and hospital records, Utstein forms and dispatcher recordings, and also changes and noise in the recordings from the defibrillator.

Primary outcome was CPR quality recorded as chest compression depth and rate, number of chest compressions and ventilations per minute, and time without chest compressions. We also noted the total time of CPR, episode length and no flow ratio: time without chest compression divided by total time without spontaneous circulation.

Statistical analysis

The four papers included different presentations and statistical data analyses. Data were gathered and organised in a spreadsheet program (Microsoft Excel 2003, Microsoft Corporation, USA) and statistical analysis in the statistical software program SPSS (SPSS 14.0, SPSS Inc., Chicago, USA). All data were examined for normality and equal variance.

In paper 1 normally distributed data are presented as mean ± standard deviation (SD), otherwise median with 25-75 percentiles. ANOVA and unpaired Student's t-test or Mann-Whitney test were used to analyse differences between the groups. Linear regression was used to evaluate changes in chest compression depth and rate with time.

In paper 2 data are presented as medians with 25- and 75-percentiles as they were not normally distributed. Mann-Whitney test was used as appropriate to analyse differences between groups.

In paper 3 normally distributed data are presented as mean ± standard deviation (SD), otherwise median with 25—75 percentiles. ANOVA and unpaired Student's t-test or Mann-Whitney test were used as appropriate to analyse differences between groups. Regression analyses were used to investigate relations between measures of quality of CPR and demographics. For cross validation of the questions in the questionnaire we used Pearson correlation analysis.

In paper 4 data were normally distributed and are presented as means with 95 % confidence intervals. Paired Students t-test was used to analyse data before vs. during transport, while unpaired analyses were used to test data before transport vs. data from episodes with no transport.

In all papers p-value of less than 0.05 was regarded as significant.

Summary of results

Paper 1

Median age was 37.5 years (range 15 - 87), 59 % were men, and 71 % reported CPR training median eight years (3 – 15) previously.

Mean compression depth was 41±11 with compression:ventilation ratio 15:2, 45±8 with compression:ventilation ratio of 30:2 and 30±8 mm with continuous compressions without ventilation . Depth was reduced as a function of time in the continuous compression group. Number of compressions per minute was 40±9, 43±14 and 73±24 and no flow ratio 49±13%, 38±20% and 1±2%, respectively.

Continuous chest compressions without ventilations gave significantly more chest compressions per minute, but with decreased compression quality. No flow ratio for 30:2 was significantly less than for 15:2.

Paper 2

Quality of CPR was available for analysis in 628 cases of out-of-hospital cardiac arrest, but only 172 episodes had at least one minute of CPR with 15 compressions and two ventilations before intubation and were included in the analysis.

In the 172 episodes we identified 3097 chest compression pauses. In 1587 (51%) of the pauses we identified two ventilations and a mean pause length for each episode was calculated. The median of these means was 5.5 s (IQR; 4.5, 7). These pauses comprised median 9% (IQR; 4%, 15%) of the time before intubation in these episodes. In 892 (29%) of the pauses we identified a different number of ventilations, or other interventions in addition to ventilation. In the remaining 618 pauses (20 %) no ventilations were registered.

Professional rescuers can deliver bag-valve-mask ventilations close to the recommended guideline time frame. Excessive time for ventilation does not explain the unwarranted pauses in chest compressions seen during CPR by professional rescuers.

Paper 3

All study subjects performed CPR well within Guidelines recommendations on all four manikins with mean compression depth 44±3mm, compression rate 101±3 min^{-1}, and 7±2 ventilations per minute.

Three quarters stated that during CPR on patients their personal sense of correct depth and force determined their performance. Fifty-five percent believed that too deep chest compressions could cause serious injury to the patient, and 39% that compressing to Guidelines recommended depth may often result in severe patient injury. A quarter felt that the potential benefits of compressing to the Guidelines depth could not justify the injuries it would cause. Breaking ribs made 54% feel very uncomfortable. 14 % gave intubation and placement of an intravenous needle high priority, and 19 % stopped chest compressions during these procedures.

Paper 4

Quality of CPR did not deteriorate during transport, but overall quality of CPR was substandard. Quality of CPR performed on site was significantly better in the episodes where transport was not initiated with ongoing CPR compared to episodes with initiation of transport during CPR. Fraction of time without chest compressions was 0.45 and 0.53 ($p= <0.001$), compression depth 37 mm and 34 mm ($p=0.04$), and number of chest compressions per minute 61 and 46 ($p=0.01$) respectively.

Discussion

Bystander CPR

Initiation of basic cardiopulmonary resuscitation by bystanders is as previously mentioned an important prognostic factor in cardiac arrest [40, 42, 45, 55]. While places with longstanding traditions in lay person CPR training far have relatively consistent rates of approximately 50% bystander CPR [76, 100], and Sweden has reported a gradual increase probably secondary to an intensive training effort [123-125], other sites report discouragingly low frequencies of bystander initiated CPR, and bystander involvement even seems to be declining [126-128]. Lately focus on reluctance to perform mouth-to-mouth ventilation has increased, and there are several reports indicating that this is a great and more and more apparent issue [127, 129].

This has been an argument for omitting ventilation from BLS. If such omission could increase the frequency of bystander CPR, and there is sufficient oxygen in the lungs and blood for at least the first few minutes, this could potentially improve outcome. In addition, although rescuer ventilation from the very beginning has been an important component of both BLS and ALS, maintenance of free airways and proper ventilation continues to cause great problems [129, 130] despite repeated efforts to improve training and techniques. However, rescuers are taught that ventilation is important and if they have technical problems, there is an impression from training sessions that they have a tendency to keep trying until they believe some air is passed.

The findings in our first study that lay persons required approximately double the time specified in the CPR guidelines for two ventilations [20, 21], support this notion. This also confirmed findings from the UK [131] and the US [132]. The new dimension in our study was that we tested a more general public place population with virtually no pre-test briefing median eight years since last training vs. immediately post-course in the other studies [131, 132].

These studies combined with animal data [113, 114] and theoretical calculations [115] supported the move from 15:2 to a 30:2 compression:ventilation ratio. In our study there were no signs that increasing the string of compressions to 30 negatively affected quality of chest compressions during the time tested. With a 30:2

compression:ventilation ratio more chest compressions are delivered per minute, but it also represent an increased workload, which again most likely will influence on the quality of CPR. It is undoubtedly physically demanding to provide good quality CPR, and with less pauses for ventilation the physical effort should be harder. Previous studies both postulate [133] and confirm [134, 135] that individual work capacity may influence CPR performance.

This is important as not only the frequency of bystander CPR affects outcome, but also the quality of the effort [46, 105, 106]. Consequently, the latest CPR Guidelines downplay ventilation somewhat with more emphasis on chest compression depth and minimum time without chest compressions [21]. It would appear that the Guidelines 2005 have taken a step in the right direction, but did they go far enough? Should lay rescuer ventilation be totally abandoned, at least for adults with sudden arrest without an obvious non-cardiac reason?

In addition to the arguments of rescuer reluctance to perform mouth-to-mouth ventilation and the relatively consistent high frequency of poor ventilation quality; continuous chest compressions without ventilation has been brought forward in a long series of experiments from the University of Arizona in Tucson [113, 116, 136, 137]. They have consistently reported better hemodynamics and improved or equal outcome in pigs receiving chest compressions only versus traditional CPR including ventilation [116, 136- 138]. It is important to note that supine swine in contrast to humans have an open airway without any rescuer intervention. Thus even without an artificial airway chest compressions in pigs gave normal minute ventilation with good arterial oxygenation [139]. This contrasts findings in humans where Safar reported that chest compressions without an actively supported airway provided no detectable passive ventilation during cardiac arrest [5]. In a study carried out on swine with the tube closed for passive inhalation, the blood was totally desaturated within two minutes [140]. Deakin et al studied possible passive ventilation from chest compressions in patients with an endotracheal tube in place and found a median tidal volume per compression of 41.5 ml (range 33.0-62.1 ml), considerably less than measured deadspace in all patients [141]. It should be noted that when these patients were studied they had a mean arrest time of

39 minutes, thus significant changes might have occurred in their chests at the time of study.

There are still limited clinical data comparing traditional bystander BLS with chest compressions only. A landmark clinical trial from Seattle randomised patients where the bystanders required telephone instructions from the EMS dispatcher to chest compressions only vs. traditional bystander BLS. The result was a non-significant trend (p=0.18) towards a higher survival rate with 14.6% in the group with chest compressions only and 10.4% in the group with standard BLS [100]. However, it has been claimed that these results cannot be extrapolated to other areas as Seattle has very high survival rates and extremely short ambulance response times (mean 4 min).

There have recently been four additional publications from other parts of the world, and none of these report higher survival rates for standard BLS that chest compressions only [142-145]. All these studies were observational, and actually confirm 15 year old data from Belgium [105] that went rather unnoticed at the time. One of the subgroups in that study received chest compressions only, and the results for this group were not different from those in the total cohort receiving standard BLS.

The Arizona group has argued strongly for the abandonment of lay rescuer ventilation in sudden cardiac arrest of likely cardiac origin in adults [146]. It is important to note that all these studies were epidemiologic, non-randomized, with the exception of the Seattle study. The latter only included bystanders who required dispatcher instructions and bystanders with the best traditional BLS techniques were probably least likely to be included. A more true randomised approach including all bystanders has therefore been called for, however difficult to achieve that is [147]. Bottom line at present is that no study hitherto published show beneficial effect of bystander ventilation.

As repeatedly stated, quality of the CPR effort matters, and in our first study quality of continuous chest compressions was substandard compared to Guidelines recommendations [20]. The depth was inadequate from the very beginning of the effort and continued to deteriorate during five minutes. We speculate that the study subjects' awareness of the fact that they were required to provide continuous chest compressions for five minutes might have made them restrain, unconsciously or consciously, resulting in overall poor chest compressions. Most other studies on fatigue and CPR quality over time have tested professionals [117-119]. As in the present study the overall tendency in such studies is a marked decrease in quality with time for continuous chest compressions, and the authors concluded that rescuer fatigue adversely affects quality of chest compressions [119].

In our study subjects performing CPR at compression:ventilation ratios of both 15:2 and 30:2 were able to compress to the recommended depth for five minutes. We do not know why quality of chest compressions did not deteriorate during five minutes of 30:2 vs. 15:2. It is possible that higher work load of more chest compressions was offset by the stress of more frequent compression-ventilation changes, particularly as lay rescuers have more problems achieving good ventilations that good chest compressions. Our data were confirmed by Yannopoulos et al [148] who tested BLS certified lay rescuers in the 2000 and 2005 Guidelines and did not find a difference in quality of CPR or in measurement of fatigue. Deschilder et al also found that quality of CPR performed was similar for the two ratios, although 30:2 was more subjectively exhausting than 15:2 [149].

Professional CPR

Also CPR provided by professionals is found to be substandard and with a high fraction of time without chest compressions [25, 26, 85], often referred to as “no flow ratio” indicating that forward blood flow rapidly disappears in the absence of chest compressions in cardiac arrest. The reasons for this high no flow ratio have barely been studied**.** A previous report found that mean time without chest compressions decreased from 61% before to 41% after intubation; a 20% absolute reduction [110]. Based on this and the knowledge of at least lay rescuers required 12-15 seconds to deliver two rescue breaths, it was hypothesised that also professionals needed excessive time to ventilate, and that this contributed substantially to the documented time without chest compressions. This hypothesis was not supported by our second study. In unintubated patients two bag-valve-mask ventilations were delivered within the 2000 Guidelines timeframe of 5-6 seconds [20], and accounted for only 9 % of the compression pauses pre-intubation. Although this increased to 15 % when adding 5.5 seconds (the median compression pause observed for two ventilations) for all other compression pauses with a different number of ventilations or other interventions in addition to ventilations, it could still not explain the high no flow ratio. These clinical results were similar to the 5 ± 1 s found in our manikin-study of two-rescuer professional CPR with bag-valve-mask. We speculate that the high fraction of time without chest compressions prior to intubation might be due to other distractions early during CPR when bag-valve-mask is being used. This could include unfavorable working conditions, moving the patient, clearing the area, establishing intravenous access etc.

A 2005 editorial in JAMA by Sanders and Ewy [146] asked "When will the Guidelines Get the Message?". This question was directed to the poor correlation between Guidelines recommendations [15, 21] and the documented quality of CPR [25, 26, 85]. Such inadequacy has previously been dismissed as an educational and training problem. Rittenberger et al has however reported that quality of CPR decreases with increasing complexity of the CPR algorithm [111], and in their editorial Sanders and Ewy comment on the increasing complexity of training courses and recommendations, and state that the guidelines assume unrealistic capabilities from the rescuers [146]. Once more these Arizona authors petitioned simplification through continuous chest compressions without ventilation, which they believed would be more likely to provide high quality CPR.

Some have also documented hyperventilation during both pre-hospital [86, 150] and in-hospital [151] resuscitation efforts. Excessive positive pressure ventilation during CPR might decrease survival by increasing intrathoracic pressure, reducing venous return and subsequent cardiac output [152]. In our study approximately 12 % of the pauses contained three or more ventilations. This was not a sign of hyperventilation as pauses with three or more ventilations were appropriately longer, 13.6 s versus 5.5 s for two ventilations with stable ventilation pattern, frequency and tidal volumes. In addition, previous reported overall ventilation rate was normal in other articles published from the same data material [26, 83, 110]. It could be that rescuers with problems performing bag-valve-mask ventilations made multiple ventilation attempts in order to achieve two satisfactory ventilations, but it seemed more likely that the many pauses with three or more ventilations were caused primarily by non-ventilation factors as discussed above, and as the seconds pass, the rescuers ventilate to maintain a guideline recommended number of ventilations per minute regardless of whether the patients were circulated or not.

There seems to be little doubt that the 2005 Guidelines took several steps in the right direction. Studies are now reporting less time without chest compression and more chest compressions per minute since the introduction of the new Guidelines [79, 153, 154]. Even more important several studies report increased overall survival after cardiac arrest and argue that this can be attributable to the recent changes in the CPR protocols [79, 155-157].

If we ignore negative and/or positive effects of ventilation as such, it is unknown whether a greater number of more shallow compressions without breaks are more or less desirable than fewer, intermittent and deeper compressions. Blood flow is reported to increase with increasing compression depth in experimental studies [158], and Babbs et al [158] reported in small 6-12 kg dogs a threshold of mean 2.3 cm under which there was no forward blood flow. Thus gains from avoiding periods without chest compressions might be lost if the quality of each compression is significantly reduced. From the same data material as in our study, Kramer-Johansen et al reported increased rate of hospital admission for increased average chest compression depth with an unadjusted OR of 1.05 (95% CI 1.01-1.09) per 1 mm increase in compression depth [83].

Our third investigation attempted to explore underlying causes for the substandard CPR quality recorded in the recent clinical studies from our group [26, 83]. To test the possibility of inadequate physical capability to perform according to Guidelines recommendations, ambulance personnel performed CPR for five minute time periods on four manikins with different chest stiffness mimicking the variable chest stiffness found in the clinical trial from the same ambulance systems [159]. In this study there was large variation with 27.5 ± 13.6 kg (mean ± SD) required to compress 38 mm in 91 patients [159]. It should also be noted that standard manikins have a linear force-depth relationship, whereas the manikins used in this present study had a non-linear relationship similar to what is found in cardiac arrest patients [159-161]. A manikin is not a human body, but these manikins at least produced a more realistic relationship between force and depth.

All tested ambulance personnel were physically capable of compressing till Guidelines depth for five minutes even with chest stiffness mimicking the mean value of the upper eighth of the chest stiffness found in the clinical study [159]. This was in contrast to the findings in the clinical study where rescuers received the same automated feedback in 108 patients and where approximately half the compressions were below Guideline limits, with mean (SD) 38 (6) mm, the lower limit in the CPR guidelines [20].

Although five minutes of CPR is shorter than most clinical episodes, the study subjects performed 20 minutes of CPR in total over a 30-35 minutes period. There was no decrease in quality with time and no difference between the first five minutes and the total CPR episode for any CPR quality variable including compression depth in the clinical study [83].

Obviously, the clinical cardiac arrest scenario is different from training and testing on a manikin, but there are also clinical studies documenting that CPR quality in accordance with Guideline recommendations is achievable [79, 80, 162]. Thus the tendency to shallow clinical chest compressions even with automated feedback [83] is probably not explained by physical inability among the ambulance personnel. Other factors must be involved.

The ambulance personnel themselves gave some indications of possible explanatory factors when answering a questionnaire. Half the personnel felt very uncomfortable when breaking ribs, 39% believed compressing till Guidelines depth [20] would result in serious patient injury, and one fourth said that the potential benefit of Guidelines depth chest compressions could not justify the harm it might cause. Most stated that it was their own sense of what was correct chest compression depth and force that determined their efforts, although only six percent claimed that the fear of causing damage limited their efforts. This might explain why they, although able to compress harder, partly ignored the feedback when treating patients [83].

The present study was designed to mimic the clinical study of Kramer-Johansen et al [83] as much as possible. The feedback system was virtually identical, thoracic stiffness were based on data from patients from the same ambulance services [159], and the study subjects were from the same ambulance services. The major difference between the studies is that manikins had taken the place of patients. This strongly indicates that results from manikin studies or training cannot simply be extrapolated to a cardiac arrest situation in patients. Other factors are involved. The answers from the questionnaire strongly indicate that emotional and mental factors influence most of them at the scene, and also that many rescuers prioritise based on their own perception of what is important.

Other aspects from the questionnaires not pertaining to chest compression depth are also worth noticing. In the clinical CPR studies there was much hands-off time without chest compressions; without feedback 48±18 % of the time [26], with feedback focused on hands-off time 40±16 % [83]. From the questionnaires two thirds thought it important to establish an IV line and intubate the patient on the scene; 10-14 % gave it top priority. One out of five stated that they stopped chest compressions during these procedures, which take time, and we speculate that it is more likely that the personnel under- than over-report on these factors. This and other similar factors therefore seem likely to contribute significantly to the previously measured long hands-off times [26, 83].

Although an ambulance service may respond to a high number of cardiac arrest per year, each paramedic in services such as Oslo and Akershus generally only responds to 2-4 cardiac arrests per year. Their limited experience with real arrest situations might also influence their performance through insecurity and hesitation in situations that are often experienced as chaotic and emotional.

Difference between best scientifically based practice and actual clinical care is one of the most consistent findings in medical research [163]. Both American and European studies [164, 165] have suggested that 30-40 % of patients do not receive care according to the present scientific evidence. There are also found gaps between groups of health personnel where doctors often ignore guidelines and look at these as unnecessary and even sometimes harmful [166]. The notion that medical procedures are uniformly performed according to established international guidelines is in many cases an illusion, and implementation of new knowledge is difficult. Kirves et al recently reported that only 44 % of 157 Finnish patients were treated according to their internal guidelines after ROSC out-of-hospital with an odds ratio of 2.5 for poor outcome with unsatisfactory prehospital postresuscitation care in multivariate analysis [167].

Olasveengen et al tried to implement the previous findings from Wik et al [26] and Kramer-Johansen et al [83] in the same ambulance services to see if it could improve their performance. This was done by presenting and emphasising the areas with greatest need of improvement to the CPR-instructors, leaving the responsibility of developing an implementation strategy to the respective instructor at the given site. Quality assessments of CPR before and after the intervention were made, but no significant differences in any of the CPR parameters were detected [168]. Several others have also documented the difficulty of implementation and alteration of attitudes and behavior [169-171].

There are articles published on various implementation strategy models [172] with several similar features. Three important phrases used by some in the science of implementation are "predisposed factors", "enabling factors" and "reinforcing factors". These include the basis of knowledge and attitudes in the population you would like to alter, the capacity and resources available to them, and behavior and opinions of others that might enhance the original effect [173].

The previous mentioned clinical data documenting CPR performance in accordance with Guidelines recommendations were from a physician-manned ambulance in Norway and highly trained staff in an Austrian hospital [79, 162]. This is very unlikely a coincidence. Both systems had long traditions in CPR research, and many of the clinically active MDs were also active CPR researchers. The presence of experienced resuscitation expertise who takes active part in the effort, can ensure the other CPR providers that breaking a rib does not hurt the patient, that chest compressions have priority over establishing an intravenous access, and who can reinforce good actions, should mean assurance and certainty for the rescuers. It also enables the ambulance personnel and in-hospital personnel to get immediate feedback on their performance, which is a typical example of the previous mentioned "reinforcement factors".

There needs to be a shared set of beliefs, attitudes and understanding among researchers, physicians and ambulance personnel before we can expect to see a consistent change in quality of CPR. An order to compress harder from a new prototype defibrillator will not even be considered by the rescuer if he or she does not know and believe that 1) chest compression depth is an important factor for survival,

2) too shallow chest compressions is a common problem in most ambulance services, 3) the modified defibrillator and feedback system measures the actual depth and 4) some broken ribs are without risk for the patient. The CPR providers cannot just be told how they are supposed to perform, they have to understand the intention behind the action and believe in it. If not, they will most probably continue to do what they have always done.

In the fourth study quality of CPR did not deteriorate during transport for all three sites combined or for any individual site. This contrasts previous findings in most manikin studies [120-122] and recent clinical findings from Oslo, Norway [174]. It should be noted that quality of CPR in the present study was generally poor with too many shallow chest compressions and approximately half the time without chest compressions even at the site of arrest. This might partly explain the lack of further deterioration with transport. It is not unreasonable to think that already poor quality CPR is less vulnerable to disturbing factors and difficult working conditions than high quality CPR.

Interestingly, quality of CPR performed on scene was significantly better in cardiac arrest episodes without CPR during transport than in episodes with initiation of transport during CPR. We therefore speculate that early decision to transport might have negatively affected CPR quality from the early stages of resuscitation. This could be due to practical preparations for transport with focus on getting the patient ready for transport to hospital rather than performing good quality CPR on site. It could also be speculated that ALS providers with less experience, less self-reliance and poorer knowledge of CPR would be more likely to transport the patient to hospital. This would be an important confounder.

Nevertheless, this is another argument against transport of the patient with ongoing CPR. Not only will the quality during transport be poor, but the CPR performed on scene before the patient is transported also appears to be affected.

Previous reports [175, 176] document that patients admitted to hospital with ongoing CPR have minimal chance of survival, and Bonnin et al concluded that there was no benefit of transporting cardiac arrest patients with ongoing CPR to hospital, with the exception of patients with hypothermia or persistent ventricular fibrillation [177]. There are two clinical exceptions to this, the recent material from Olasveengen et al with five percent survival to hospital discharge among patients transported to hospital with ongoing CPR [174], and an article from Austria [178] including both in- and out-of-hospital cardiac arrest with 31% ROSC and 6% with favorable long-term outcome in this group. In the study by Olasveengen et al half the patients had ROSC on scene, but rearrested during transport with CPR restarted for the rest of the transport [174].

Another important aspect is the safety of ambulance personnel when performing CPR during transport weighed against any potential benefit for the patient. This is clearly problematic, and is now also included as an ethical issue in the European Guidelines [21].

With all this knowledge it should be unnecessary to still transport patients during ongoing CPR, at least without the help of mechanical chest compression devices. Although this has yet not been shown to improve outcome, it should eliminate some safety risks to the personnel in the moving vehicle.

Hick et al [179] found that non-medical factors, such as place of arrest and environmental factors, influence our decision the most whether or not to transport the patient to hospital during ongoing CPR. In the questionnaires from Akershus and London 22% answered that they would take the patient to hospital during ongoing CPR if family and friends of the patient wished so. Also if the distance to hospital was short, 16% would transport the patient. Differences between ambulance services in the tradition for transporting pulseless cardiac arrest patients to hospital with ongoing CPR is probably illustrated in the present study as the frequency was five times as high in site 2 as in site 1.

If transport to hospital with ongoing CPR is to be of any value, there must be some additional treatment alternative in-hospital that cannot be administered out-of-hospital. Until such treatment can be shown to improve outcome, ALS providers should be encouraged to “stay and play”, allowing them to focus on delivering adequate ALS on scene until the resuscitation effort is terminated or spontaneous circulation returns.

Future perspectives

Quality of CPR is important for outcome and survival after cardiac arrest [46, 47, 107] and is currently substandard at most sites both out-of and in-hospital [25, 26, 85]. More research is needed, but also implementation has to be increasingly emphasised. As long as the generated knowledge does not force the needed changes in mind settings, attitudes and behavior, the survival rates will most probably remain low. We have to make all CPR providers, both lay responders and professionals, understand the importance of their intervention and contribution in cases of cardiac arrest so that they believe in their effort when based on the science of resuscitation. We have to make the recommendations manageable and educational so that they believe in themselves and their knowledge and skills the day a family member, a friend, an acquaintance or a complete stranger collapse in their presence.

I also believe that much can be done in making CPR training scenarios more realistic so that rescuers are both physically and mentally more prepared the day they actually have to take action. The training environments are to a great extent class rooms where the course participants find their "patient" on the floor with plenty of space around, they have a pillow underneath their knees and they start and stop at preferred times. In many cases they also have an instructor guiding and correcting them while providing CPR. It is important to create a certain feeling of being in control, but if the move from this artificial training setting makes them panic and feel that they do not know what to do the day someone collapse in their presence, it is of no use. Swor et al found in a retrospective study that only a minority of trained lay people actually performed CPR if exposed to a real cardiac arrest. The most common reasons for not performing CPR were panic, perception that they would not be able to perform CPR correctly, and fear of hurting the patient [103]. Axelsson et al interviewed lay rescuers who had performed CPR and most reported a feeling of humanity, obligation and courage as causes of initiation of CPR. At the same time they felt exposed, deserted, powerless and ambivalent as to whether what they did was correct [180].

Although patients are different from manikins, some factors could make training more realistic. In real cardiac arrest there are many stressors and disturbing factors as the lay rescuers interviewed by Axelsson [180] described. Both intellectual and emotional stressors are undoubtedly present and also practical difficulties like getting the patient down on the floor and physical difficulties getting in the right position etc. All these factors can contribute to irresolution and doubt as to whether they should do something and if so, what. The training scenarios should if possible prepare rescuers more for this. There should be a certain pressure on initiative and performance, emotional stress like presence of other bystanders or family members, noise and other potentially distracting factors, and rescuers should feel a little exposed and deserted to provoke some of the feelings a real cardiac arrest might give. Post-session debriefing can enable constructive feedback with focus on learning and mastering.

Feedback and debriefing in combination are shown effective [181] in in-hospital cardiac arrest and will probably be incorporated in more hospitals and ambulance services in the years to come. A prerequisite is that quality of CPR is measured. Defibrillator technology has made this possible, but still there is a long way until this is standard in most hospitals and ambulance services.

Strategic and educational implementation through changes in attitudes and believes, more realistic training scenarios and continuous assessment of CPR quality with automated feedback as well as personal debriefing are all key points to improve quality of CPR and important things to emphasise in the future.

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Papers