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The addition of voice prompts to audiovisual feedback and debriefing does not modify CPR quality or outcomes in out of hospital cardiac arrest – A prospective, randomized trial☆

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ABSTRACT

Aims: Chest compression quality is a determinant of survival from out-of-hospital cardiac arrest (OHCA). ERC 2005 guidelines recommend the use of technical devices to support rescuers giving compressions. This prospective randomized study reviewed influence of different feedback configurations on survival and compression quality.
Materials and methods: 312 patients suffering an OHCA were randomly allocated to two different feedback configurations. In the limited feedback group a metronome and visual feedback was used. In the extended feedback group voice prompts were added. A training program was completed prior to implementation, performance debriefing was conducted throughout the study.
Results: Survival did not differ between the extended and limited feedback groups (47.8% vs 43.9%, $p = 0.49$). Average compression depth (mean ± SD: 4.74 ± 0.86 cm vs 4.84 ± 0.93 cm, $p = 0.31$) was similar in both groups. There were no differences in compression rate (103 ± 7 vs 102 ± 5 min(−1), $p = 0.74$) or hands-off fraction (16.16% ± 0.07 to 17.04% ± 0.07, $p = 0.38$). Bystander CPR, public arrest location, presenting rhythm and chest compression depth were predictors of short term survival (ROSC to ED).
Conclusions: Even limited CPR-feedback combined with training and ongoing debriefing leads to high chest compression quality. Bystander CPR, location, rhythm and chest compression depth are determinants of survival from out of hospital cardiac arrest. Addition of voice prompts does neither modify CPR quality nor outcome in OHCA. CC depth significantly influences survival and therefore more focus should be put on correct delivery. Further studies are needed to examine the best configuration of feedback to improve CPR quality and survival.
Registration: ClinicalTrials.gov (NCT00449969), http://www.clinicalTrials.gov.

1. Introduction

Success of pre-hospital cardio-pulmonary resuscitation (CPR) depends on many factors. Quality of chest compressions has been identified as one factor affecting survival after CPR. Kramer-Johansen et al. showed that deeper chest compressions were associated with improved short term survival (admission to hospital).[1] Christenson et al. demonstrated that compression fraction (time with compressions relative to total resuscitation duration) is an independent predictor of survival.[2] Automated feedback systems were able to improve the quality of resuscitation, but the ideal configuration of a feedback system has not yet been identified.[1]

We investigated the effect of adding voice prompts to a metronome and visual depth feedback on the quality of chest compressions in a two arm, randomized, pre-hospital study. We hypothesized that the addition of this feedback-element would improve CPR quality and affect return of spontaneous circulation (ROSC).

2. Methods

The study was approved by the Ethics Committee of the Regional Medical Board of Registration (Ärztekammer Westfalen Lippe)

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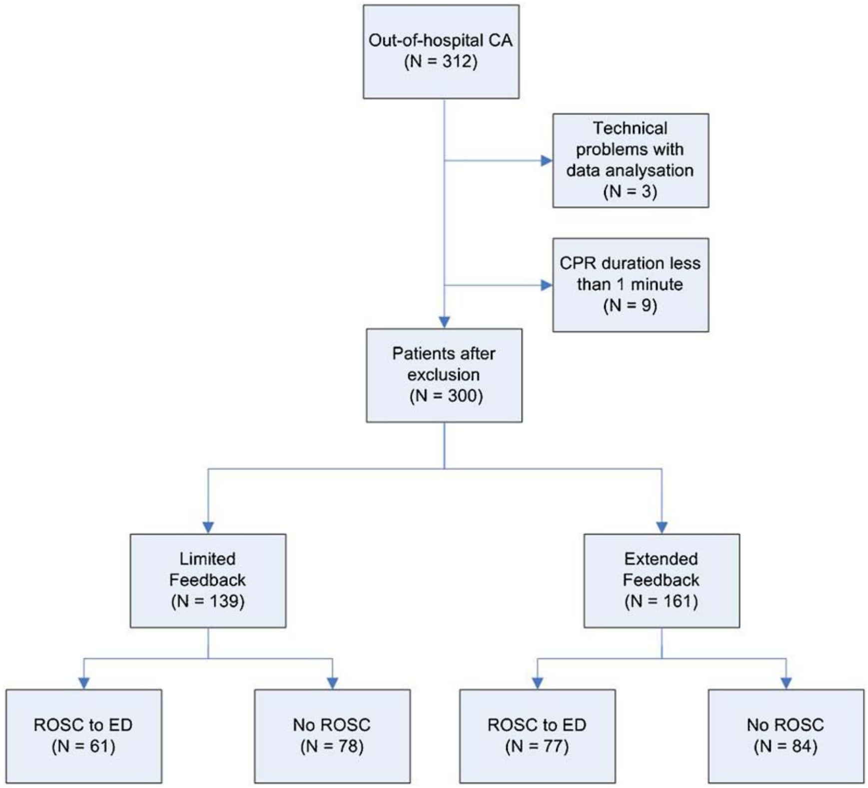

Fig. 1. Participants_Flowchart.

and the University of Münster (Westfälische Wilhelms-Universität Münster, Record ID: 2006-671-f-S). The study was registered at clinicaltrials.gov with the identifier NCT00449969. The study population included all out-of-hospital arrests (unresponsive, pulseless and apneic and treated with either CPR or defibrillation) 18 years of age or older. Analysis was performed on 312 consecutive cardiopulmonary resuscitations occurring between April 2007 and April 2009 in the city of Muenster, Germany with a population of 280,000. Of these, 12 cases could not be analysed – three because of technical problems (corrupted data files) and nine because of chest compression durations of less than 1 min (Fig. 1). Data collected included patient care reports as well as digital ECG and compression signals recorded by the automated external defibrillators (AED) used by ambulance personnel and physicians. The study was performed in a physician-based emergency medical service (EMS) run by a professional fire department, performing between 150 and 180 resuscitations annually.

The feedback system used in this study was an AED with an accelerometer integrated into the defibrillation pads recording the rate and depth of chest compressions (AED Pro with CPR-D Padz, ZOLL Medical Corporation, Chelmsford, MA, USA). The accelerometer sensor is placed in the middle of the sternum at the compression point. This method has been described in previous studies.[1,3,4] The feedback system provides auditory and visual prompts guiding chest compressions during CPR. Chest compression quality data is recorded based on the uniform reporting standard described previously[4] within the technical capabilities of the equipment. Feedback consisted of either a visual bar graph indicating chest compression depth combined with an acoustic metronome alone (Limited) or the visual indicator and acoustic metronome combined with verbal prompts (Extended). The configuration of the verbal prompts is displayed in Table 1.

Simulation studies have demonstrated that training and education in the use of a feedback system are important requirements.[5,6] All team members were therefore trained in the use of the feedback system prior to the beginning of the study.

Training began with a 90 min lecture about the importance of chest compressions according to guidelines recommendations in the generation of blood flow. With an emphasis on the importance of limiting pauses in compressions to a minimum. The lecture additionally covered the phenomenon of “stress” and “attention overload” and included examples of how to minimise errors under difficult circumstances. Feedback systems were introduced as a method of improving the quality of resuscitation in terms of pauses, frequency and depth of chest compressions. Lectures were followed by 90 min of simulated resuscitation scenarios with and without use of a feedback system. All participants were able to recognize how usage of a feedback system improved CPR-quality. Introduction of the feedback-system was postponed until all firefighter/EMT’s and physicians had completed training. As part of routine clinical quality management, each resuscitation-attempt was reviewed jointly by the involved team and the medical management of the EMS system. This debriefing was used to remind teams that quality of chest compressions has an influence on outcome.[1–3] Additionally, teams used the review to discuss their performance and to describe the outside influences during the case. Teams regularly received a printed copy of the performance evaluation.

At the end of patient recruitment digital records were analysed and compression performance parameters were calculated using software from the AED manufacturer (CodeNet CodeReview v4.1, ZOLL, Chelmsford, USA). The primary outcome measure was survival to Hospital Emergency Department (ED), defined as arrival to the ED with a stable, perfusing rhythm, the duration of which was at least 20 min (ROSC to ED). Clinical data were obtained from the German Resuscitation Registry (Deutsches Reanimationsregister, http://www.reanimationsregister.de). Long-term survival data were not available for publication due to legal restrictions.

Table 1
Overview feedback cohorts.

Audio prompts	Prompts given when	Group 1: limited feedback	Group 2: extended feedback
"Continue CPR"	Post shock	OFF	ON
"Continue CPR"	Post ECG analysis and "No Shock" indication	OFF	ON
"Start CPR"	10 s without initial chest compressions after AED is switched on	OFF	ON
"Push harder"	10 chest compression lower than 38 mm	OFF	ON
"Good compression"	10 cc between 38 and 50 mm after "Push harder" prompt	OFF	ON
"Continue CPR"	15 s without chest compressions	OFF	ON
Metronom with 100 cc/min	Continuously only when chest compression is performed	ON	ON

CPR process variables measured were: compression rate, compression depth, and hands-off fraction (time without chest compressions relative to CPR duration). These variables are shown in Table 2.

All data analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) presenting descriptive statistics and frequencies. Logistic regression modeling using backwards stepwise selection was performed on all CPR process variables, excluding the least significant covariates one at a time. Because of the binary dependent character of the result ROSC, we used the log odds ratio for ROSC (probability of achieving ROSC) with a logistic regression modell (LogIt-Modell, Fig. 2).

AED were programmed to provide either Limited or Extended feedback. A total of 16 AED, 8 with Limited and 8 with Extended feedback (see Table 1), were randomly assigned to cover all 16 ambulances in service in the city of Münster. AED were randomly re-assigned to different vehicles on a monthly basis. A total of 241 firefighter-EMT working in 24/48 h shifts can be assigned to any of these ambulances. They also alternate between rescue and fire service. Ambulances responded to both Basic- and Advanced Life Support (ALS) calls. In case of an ALS call a Physician's Car is responding in parallel. The two Physician's Cars are each staffed by a firefighter-EMT and one of 54 emergency physicians performing two to three shifts per month, in addition to their regular duties at the hospital. Due to this constant rotation non of the 312 consecutive cardiopulmonary resuscitations was covered by the same four providers team. Within the team the task of chest com-

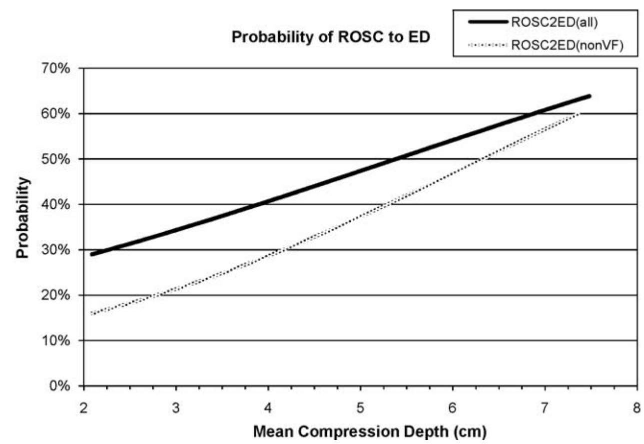

Fig. 2. Probability of ROSC to ED.

Table 2
Utstein characteristics and feedback groups.

	All patients	Limited feedback	Extended feedback	*p*-Value
Resuscitation attempts	300	139	161	
Status				
Unwitnessed or unknown	133 (44.3)	59 (42.4)	74 (46)	0.827
Bystander witnessed	150 (50)	72 (51.8)	78 (48.4)	
EMS witnessed	17 (5.7)	8 (5.8)	9 (5.6)	
Start of CPR				
Bystander CPR	86 (30.6)	42 (32.8)	44 (28.8)	0.463
CPR started by EMS	195 (69.4)	86 (67.2)	109 (71.2)	
Arrest type				
Traumatic	8 (2.7)	5 (3.6)	3 (1.9)	0.478
Non-traumatic	292 (97.3)	134 (96.4)	158 (98.1)	
Arrest location				
Home/Residence	206 (68.7)	93 (68.4)	113 (70.4)	0.676
Public	90 (30)	43 (31.6)	47 (29.4)	
Age, mean (SD), y	68.24 (16.09)	67.81 (14.81)	68.61 (17.15)	0.385
Gender				
Women	94 (31.3)	41	53	0.524
Men	206 (68.7)	98	108	
Presenting rhythm				
Sinus	26 (8.7%)	10 (7.2)	16 (9.9)	0.105
VF/VT	88 (29.3)	49 (35.3)	39 (24.2)	
PEA	20 (6.7)	5 (3.6)	15 (9.3)	
Asystole	160 (53.3)	72 (51.8)	88 (54.7)	
Unknown	6 (2)	3 (2.2)	3 (1.9)	
Time from Emergency call to Arrival at Scene (SD), min	6.1 (2.31)	5.67 (2.42)	6.21 (2.38)	0.053
ROSC to emergency department				
ROSC	138 (46)	61 (43.9)	77 (47.8)	0.495
No ROSC	162 (54)	78 (56.1)	84 (52.2)	
CC depth mean (SD)	4.792 (0.9)	4.847 (0.93)	4.744 (0.86)	0.316
Compression rate mean (SD)	103.35 (6.58)	102.98 (5.25)	103.67 (7.53)	0.743
Fraction without CC % (SD)	16.75 (0.72)	17.04 (0.074)	16.16 (0.07)	0.388

All numbers in parentheses are percentages unless otherwise noted. *p*-Value: Mann–Whitney *U* or *T*-test.

Table 3
Utstein characteristics and ROSC to ED.

	All patients	ROSC to ED	No ROSC to ED	p-Value
Resuscitation attempts	300	138 (46.0)	162 (54.0)	
Status				
Unwitnessed or unknown	133	38 (28.5)	95 (71.5)	
Bystander witnessed	150	89 (59.3)	61 (40.7)	
EMS witnessed	17	11 (64.7)	6 (35.3)	
Start of CPR				
Bystander CPR	86	50 (58.1)	36 (41.9)	0.0049
CPR started by EMS	195	78 (40)	117 (60)	
Arrest type				
Traumatic	8	1 (12.5)	7 (87.5)	
Non-traumatic	292	137 (46.9)	155 (53.1)	
Arrest location				
Home/residence	206	83 (40.2)	123 (59.8)	0.0075
Public	90	52 (57.7)	38 (42.3)	
Age				
Age, mean (SD), y	68.24 (16.09)	70.4 (17.4)	67.7 (14.9)	
Gender				
Women	94	41 (43.6)	53 (56.4)	
Men	206	97 (47)	109 (53)	
First rhythm				
AED shock	88	68 (77.3)	20 (22.7)	<0.0001
AED no shock	212	70 (33.0)	142 (67.0)	
CPR quality				
CC depth mean (SD)	4.792 (0.9)	4.89 ± 0.82	4.70 ± 0.87	
Compression rate mean (SD)	103.35 (6.58)	103.25 ± 5.76	103.45 ± 7.05	
Fraction without CC % (SD)	16.75 (0.72)	17.04 ± 0.08	16.03 ± 0.07	

All numbers in parentheses are percentages unless otherwise noted. p-Value: Fisher's exact test.

pression was performed by each member, changing every 3 min. Individual impairment of providers can therefore be excluded. Both BLS-ambulances and Physician's Cars used the feedback-AED during the whole resuscitation attempt. Device randomization was un-blinded after completion of data collection and analysis and was not known to the investigators.

Based on the work of Wik et al.[7] the resuscitation algorithm used in the Münster EMS system requires an initial CPR cycle of 3 min duration. The AED will prompt to interrupt chest compressions after every 3 min of CPR for rhythm analysis and, if required, defibrillation. This leads to an algorithm that facilitates coordination of rhythm analysis, drug therapy, and switching of personnel. Drug therapy and airway management were in accordance to ERC 2005 guidelines.[8,9]

Quality data (mean compression depth, mean compression rate, and hands-off fraction) were downloaded after every case using a USB interface. Data was centrally stored and identified only by incident number after removing patient identifiable information. Association with the Utstein style data collected in the German Resuscitation Registry (Deutsches Reanimationsregister) was performed using spreadsheet software (Excel, Microsoft Corporation, Redmond, WA, USA). Every case was initially analysed using the manufacturer's software and was then validated by the investigators.

3. Results

The Utstein and demographic characteristics of the resuscitation attempts are comparable in both groups as presented in Table 2. Statistical comparisons were also made between these parameters for endpoint ROSC to ED vs non-ROSC to ED (Table 3).

We found no differences between the Limited and Extended feedback groups with regard to chest compression quality. The results are shown in Table 2. Overall performance deviated minimally from ERC 2005 guidelines for chest compression quality.

The almost identical quality of chest compressions in both arms did not lead to a difference in ROSC to ED between the two feedback groups.

Retrospectively, 300 cases were analysed with regard to the effect of mean compression depth on short-term survival (ROSC to ED, Table 4). An average chest compression depth of 5–6 cm showed the highest ROSC rates.

In a further sub-group analysis, we repeated this for the 212 cases that did not have ventricular fibrillation (VF) as initial arrest rhythm. We performed a logistic regression analysis on both data sets, using the software package NCSS 2007 (NCSS, Kaysville, UT, USA). For all cases, the logistic regression model was $-1.465 + .2719^{*}\text{cm}$ (95% CI 0.01404-0.52973, $p < 0.04$). For cases that did have initially non-shockable presenting ECG rhythm, the logistic regression model was $-2.478 + .3919^{*}\text{depth}$ (95% CI 0.07423–0.70952, $p < 0.02$). Plots of both models can be found in Fig. 2. Using these regression models, a short term survival rate (ROSC to ED) of 50% for all cases would be achieved with a compression depth of 5.38 cm (2.1 in.), while for non-shockable presenting ECG cases, a compression depth of 6.32 cm (2.5 in.) would achieve a 50% survival to ED rate.

4. Discussion

Wik et al. in their landmark study of resuscitation quality (using ERC 2000 guidelines) published sobering data about CPR performance in professional rescue services. Only 28% of chest compressions were in the target range of 38–51 mm. The effective compression rate was only 64/min, and the hands-off fraction was 48%.[3] These results prompted us to measure and improve the quality of chest compressions.

In comparison to Wik's results compression depth and rate both with Limited and Extended feedback were adhering closer to ERC 2005 guidelines in our study cases (Table 2). Hands-off fraction was less than in other published studies.[1,3,6] The low fraction of 16.75% (Table 2) may partly result from this study being conducted in accordance with 2005 guidelines, which limit shock delivery to a single shock instead of a series of shocks. Additionally, all patients received endotracheal intubation during the resuscitation attempt. This resulted in continuous chest compressions without ventilation pauses. Although ERC guidelines 2005 recommend the use of

Table 4
ROSC to ED and CC depth.

CC depth in cm (mean)	All cases		AED shock		AED no shock	
	ROSC to ED	No ROSC to ED	ROSC to ED	No ROSC to ED	ROSC to ED	No ROSC to ED
2.00–2.99	1 (16.7)	5 (83.3)	1 (100)	0 (0)	0 (0)	5 (100)
3.00–3.99	15 (29.4)	36 (70.6)	7 (70)	3 (30)	8 (19.5)	33 (80.5)
4.00–4.99	65 (49.6)	66 (50.4)	32 (80)	8 (20)	33 (36.3)	58 (63.7)
5.00–5.99	45 (54.9)	37 (45.1)	23 (82.1)	5 (17.9)	22 (40.7)	32 (59.3)
6.00–6.99	9 (36)	16 (64)	2 (33.3)	4 (66.7)	7 (36.8)	12 (63.2)
7.00–7.99	3 (60)	2 (40)	3 (100)	0 (0)	0 (0)	2 (100)
Total (%)	138 (46)	162 (54)	68 (77.3)	20 (22.7)	70 (33.0)	142 (67.0)

All numbers in parentheses are percentages unless otherwise noted.

technical devices to support rescuers giving chest compressions with feedback,[8] currently these devices are mostly used in skill training.[15–17] However, these results could only be partially translated into OHCA practice especially since some simulator-studies were designed for in-hospital-CPR. Using a real-time automated feedback-system, Kramer-Johansen et al. were able to increase the percentage of compressions with adequate depth from 24% to 53%. The mean compression rate decreased from 121/min to 109/min and the hands-off fraction decreased from 48% to 45% in the feedback group.[1]

As found in numerous previous studies, resuscitation characteristics of bystander CPR,[10] location of cardiac arrest,[11] age[12,13] presenting rhythm[14] and chest compression depth[1] are significantly correlated to ROSC.[10]

In this study the intervention group (Extended feedback) received voice-prompts about compression quality in addition to a metronome and visual feedback. The control group (Limited feedback) was guided by metronome and visual feedback only. We could not find differences regarding compression quality and ROSC between Extended and Limited feedback. Compression depth, frequency, hands-off fraction and ROSC were similar in both groups.

Our system of intensive training prior to the introduction of real time automated feedback and ongoing debriefing after each case may have contributed to the high quality of chest compressions. Further improvement by addition of voice prompts guiding compression quality could not be identified. Guideline-adherence regarding chest compression depth, frequency and pausing was high in both groups. It can therefore be assumed that direct feedback about rate and depth, if accompanied by training and performance reviews, can lead to high quality compressions during OHCA leaving no room for further improvement by additional voice prompts. It cannot be excluded that provision of feedback mainly prevented loss of the previously trained skills.

An other limitation of this study is the randomization at the level of the device. It is possible that rescuers used both types of devices during the study period and gained abilities that were then carried over to resuscitations in which there was no voice feedback.

Olasveengen et al. failed to improve chest compression quality by using real-time automated feedback and performance evaluation. The authors state that on-scene usage of the device without previous training may have contributed to this negative result.[6]

With regard to the staff roster of our study, including constant team-changes and low case-load of annually 150–180 resuscitation attempts responded by 241 firefighter/EMT, it is unlikely that the effect of training by usage of the feedback system led to a significant bias. However this effect might be present and limits conclusions from the results.

In our study, extended feedback with voice prompts also did not impair performance compared to limited feedback. As these voice prompts may have beneficial effects in users with less extensive training, there appears to be no reason to eliminate these prompts. Further research is needed to study the human-machine interface in resuscitation.

The high quality of chest compressions in both groups may have contributed to high ROSC rates above the average of other studies on OHCA. Differences in ROSC were not identified between the two study arms. This can be explained by the fact that compression quality did not differ between feedback groups and was close to ERC 2005 guideline recommendations. Earlier studies show that ROSC is highly dependent on chest compression quality. Christenson et al. reported that chest compression fraction is an independent predictor of increased survival.[2] The study group of Abella et al. found improved ROSC rates in patients with in-hospital CA receiving chest compressions at a rate of more than 90/min.[20] Due to the large differences in terms of patients and CPR-providers this in-hospital-study cannot be equated to OHCA.

It has been shown in very early animal-studies that cardiac output and blood flow depend on compression depth and that compressions of less than 2 cm depth resulted in no measurable blood flow.[21] Similar to the findings of Kramer-Johansen et al. who showed that survival increased with increased compression depth,[1] we found a significant correlation between ROSC and compression depth in a post hoc analysis (Fig. 2).

Although the logistic regression analysis method is unable to imply causality, two key observations can be made. In the model for all cases a short-term survival probability of 50% is not reached until compression depths reaches at least 5.4 cm, while for patients presenting with non-shockable rhythms, the depth is slightly greater at 6.1 cm for a 50% short term survival probability. To further increase the probability of ROSC to ED, even deeper compressions appear to be necessary. The model for cases that did not present with VF shows that even deeper compressions are required here to obtain comparable outcomes.

ERC 2005 guidelines recommended compression depths between 38 mm and 51 mm. It has been suggested previously that a compression depth of 51 mm and above may result in better outcomes.[1] Our data appear to support this (Table 4). However, compression depth cannot be increased indefinitely since maximum compression depth will be limited by an increased risk of injury at some point. It is therefore important that a rescuer can be guided to compress at a required minimum depth but also be prevented from exceeding a safe maximum. What that safe maximum is needs to be investigated in future studies in which actual compression depths are continuously recorded.

Previous studies have shown that improvement of CPR cannot be achieved by technical means alone and that feedback mechanisms have to find a balance between guidance and distraction. Dine et al. showed in a in-hospital simulation manikin study that the combination of feedback and debriefing led to better chest compression quality than feedback alone.[5] Abella et al. described how the complexity of resuscitation scenarios increases the probability of human error, leading to decreased performance.[18] The effect of stimulus saturation limits the recognition of signals during complex situations such as a resuscitation. This effect can lead to annoyance and performance reduction.[19] Like in aviation, reducing human error needs to be achieved by a combination of technical means, training and debriefing.

It remains unclear how feedback-systems should be configured in order to optimize quality.[1,3] Insufficient data exists to review single elements of feedback technology in terms of their benefit. Feedback systems are equipped with many different elements for guidance. Rate guidance can be provided by an acoustic and/or visually prompting metronome. Depth guidance can be provided via visual feedback, e.g. moving bar graphs, or voice-prompts. The rescuer may be alerted to shallow compression or incomplete release. Evaluating the different underlying measurement technologies was not the aim of this study.

5. Conclusions

In our physician-based professional EMS system usage of feedback technology combined with training and debriefing improved chest compression quality, guideline adherence and high ROSC-rates. Even limited CPR feedback leads to high chest compression quality.

As previous studies described epidemiological aspects like bystander CPR, location, rhythm and chest compression depth are determinants of survival from out of hospital cardiac arrest.

Overall the single addition of voice prompts to the CPR-feedback did not modify CPR quality or outcome in this study.

Since CC depth is a predictor of short term survival more focus should be put on high quality chest compression, especially in BLS education. Quality of chest compressions has not been documented in past landmark studies.[22,23] For future interventional studies on the subject of resuscitation, documentation of compression quality should be required to identify bias due to poor compression quality.[24]

Different elements of feedback technology should be carefully studied prior to introduction into clinical practice. Not every technical progress will lead to improved compression quality.

In the future, technical developments such as ECG analysis and defibrillation during chest compressions could additionally lead to decreases in hands-off fraction.[25]

Conflict of interest statement

The corresponding authors have no conflicts of interest.

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