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New visual feedback device improves performance of chest compressions by professionals in simulated cardiac arrest☆

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ABSTRACT

Introduction: Quality of external chest compression (ECC) is a key component of Basic Life Support. Different approaches to improve rescuers' performance have been evaluated, but few attempts have been made to invent simple devices to improve performance. This study evaluates a new visual feedback system for ECC for healthcare professionals.

Methods: Ninety-three healthcare professionals volunteered (14 emergency medical technicians, 45 paramedics, 34 physicians; age 32 ± 7.2 (range 21–61); 72% male) in this randomized cross-over study. All subjects were tested on a manikin (Skillreporter ResusciAnne®, Laerdal, Stavanger, Norway) in identical mock cardiac arrest scenario and asked to perform 2 min of continuous ECC (secured airway): Group A ($n = 46$): ECC with device first, followed by ECC without device a minimum of 45 min later; group B ($n = 47$): vice versa. Primary endpoints: mean compression rate 90–120 min^{-1}; mean compression depth 38–51 mm. Data were analyzed using repeated measure logistic regression model for binary categorized endpoints and repeated measure ANOVA test for continuous endpoints.

Results: Correct compression depth was achieved by 45.2% of subjects (95%-CI: 30.5–64.9 mm) without vs. 73.1% (95%-CI: 40.3–57.4 mm) with device ($p < 0.001$); correct compression rate was achieved by 62.4% (95%-CI: 78–147.8 min^{-1}) without vs. 94.6% (95%-CI: 87.3–126.6 min^{-1}) with device ($p < 0.001$). Overall, 85% of the subjects thought the feedback system was helpful and 80.6% would use it if available.

Conclusions: The new visual feedback device significantly improved ECC performance (compression rate and depth) by healthcare professionals in simulated cardiac arrest. Most participants found the device easy to use.

1. Introduction

It is unquestioned that well-performed external chest compression (ECC) is key for improved outcomes in cardiopulmonary resuscitation (CPR). While there is little evidence about the best method, it is likely that 2005 guidelines' recommendations[1,2] are a feasible compromise.

Published data show extremely poor ECC performance by healthcare professionals, especially regarding rate and depth of compressions. Recently Wik et al. observed a mean compression depth of 34 mm in out-of-hospital resuscitations, and only 28% of compressions within 38–51 mm.[3] In addition, Aufderheide et al. found that healthcare professionals in simulated cardiac arrest demonstrated poor performance in compression depth in an assessment of different manual chest compression–decompression techniques.[4]

Improvement in CPR quality was determined to be beneficial in combination with defibrillation using real-time feedback with CPR,[5] but this technology has not been well-established in out-of- or in-hospital settings. In both settings, especially at the beginning of resuscitation, the use of automated external defibrillators (AED) is of increasing importance, but monitoring and providing feedback on CPR quality is not currently standard of care. The development and evaluation of a stand-alone system used by professionals or trained first responders seem necessary to strengthen the chain of survival.

The present study evaluates a new feedback system in simulated cardiac arrest based on improvement in ECC performance and acceptance by healthcare workers.

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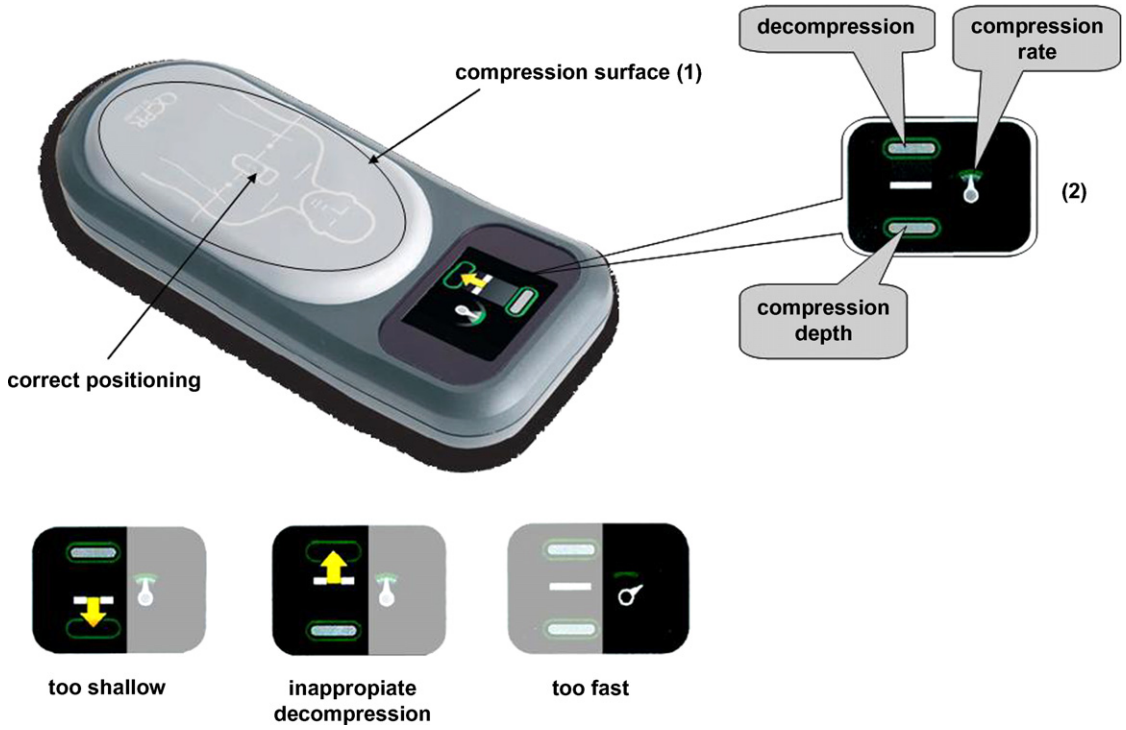

Fig. 1. Feedback system and its functionality. Device with functions. The compression surface (1) and the feedback monitor (2).

2. Materials and methods

As no potential harm to study participants was expected, the local institutional review committee solely required informed consent from each participant prior to the study. Each subject was informed about the study via standardized leaflet and told that their performance would be evaluated. Each participant provided written consent for data acquisition and analysis.

2.1. Tested device

The tested feedback device (prototype by Laerdal, Stavanger, Norway) measures 152 mm × 64 mm × 28 mm and is designed to be placed between victim's chest and rescuer's palm (Fig. 1). The upper surface of the device has a grey hard rubber cover, which is used as contact surface for the rescuer's hand. Feedback information is provided by a 26 mm × 26 mm coloured display. Compression depth is represented by a white bar, moving up and down between two green fields, which turn to grey when reached by the bar. Compression rate is shown by a display similar to a tachometer: if the pointer is positioned in the green range it is zoomed in and illuminated (see Fig. 2). Visual feedback is based on information provided by integrated accelerometer and pressure sensors. The device provides real-time feedback of user performance and compares it to preset target values (provided by manufacturer) for rate and depth of compression. Rate is based on the three previous compressions.

2.2. Data analysis

Primary endpoints were adapted from current guidelines[2]: average compression depth 38–51 mm; rate 90–120 min^{-1} (Fig. 3).

Attribute and Symbol	inappropriate	Correct	correct range
compression depth 	The bar does not reach the lower field or goes too far. A yellow arrow indicates the direction of necessary correction.	The bar reaches the lower field. The field is be illuminated with each contact.	38-51 mm
decompression 	The bar does not reach the upper field. A yellow arrow indicates the direction of necessary correction.	The bar reaches the upper field. The field is illuminated with each contact.	< 2.5 kg
compression rate 	The tachometer points beyond the green range and is shaded.	The tachometer points inside the green range and is illuminated.	90-120 min^{-1}

Fig. 2. Visual feedback by the device. Visual feedback by the device.

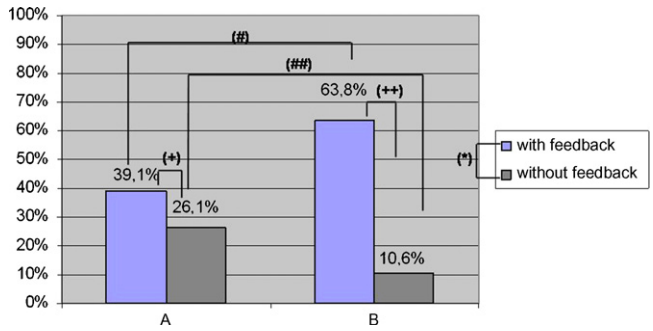

Fig. 3. Overview results of sufficiency between groups. Faultless compressions > 80% of total compressions and mean compression rate between 90 and 120 min^{-1} with and without feedback in Group A and B. (*) $p < 0.0001$; (+) $p = 0.1797$; (++) $p < 0.0001$; (#) $p = 0.0227$; (##) $p = 0.0645$.

Secondary endpoints: incomplete release of pressure between compressions; overall efficacy of ECC performance. Additionally, subjects' opinions on use of the device were queried. Subjective fatigue was evaluated immediately after testing using a visual analogue scale ranging from 1 "absolutely fit" to 10 "completely exhausted".

2.3. Statistical considerations

Required sample size was calculated from data gathered in a pilot study. With an observed success-proportion of 43% in mean compression depth and expected drop-out rate of 10%, this calculation found 80% power to achieve a 5% two-tailed significance level in a sample size of 48 subjects for each group.

Randomization was achieved by a random list generated by SAS-Macro (SAS Institute Inc., Cary, NC, USA, Version 9.1.3) using permuted blocks with a random length of 2, 4 or 6 to ensure allocation balancing.

2.4. Study protocol

In this prospective randomized cross-over study, subjects were recruited at an education session for Emergency Medical System (EMS) professionals and evaluated on the same manikin (Skillreporter ResusciAnne®, Laerdal, Stavanger, Norway) in a mock cardiac arrest scenario with standardized instruction: *"Please perform continuous chest compression (CCC)-CPR like you would do on a patient with a secured airway. Continue for 2 min without any interruption. Please start and stop immediately when instructed."*

Subjects were randomly assigned to one of the study groups and asked to perform 2 min of continuous ECC (the airway was secured in the scenario): Group A: ECC with the device first followed by ECC without feedback a minimum of 45 min later; Group B: vice versa.

All subjects received standardized explanation (30 s maximum) concerning feedback features of the device using pictures and demonstration, and approximately 30 s of device familiarization without further instruction.

2.5. Measurement and data acquisition

The manikin was placed on the floor and connected to Laerdal PC SkillReporting software (Version 1.3.0, Laerdal, Stavanger, Norway) for data acquisition. According to the default settings of the device, a compression depth of 38–51 mm was assessed as correct, incomplete release by more than 10 mm was considered inappropriate. Compression rate between 90 and 120 min^{-1} was accepted, as the device was programmed according to 2005 guidelines.

The percentage of compressions falling into each category (too deep/shallow, inadequate decompression, etc.) is reported in relation to the total number of compressions performed in each session. One compression can be counted in several categories if it meets those criteria. For example, one compression would have been recorded as too shallow and inappropriately decompressed if both criteria apply. Thus, a single compression can count several times.

Demographic data was obtained with a standardized questionnaire. A specific test-related questionnaire was completed by the subjects immediately after the corresponding test.

2.6. Statistical analysis

Continuous variables are reported as means ± standard deviation (SD), categorical data as frequencies and percentages. Repeated logistic regression models were used to analyze all endpoints with a binary outcome, including primary endpoints of mean compression rate and mean compression depth.

Repeated measure ANOVA tests were used for continuous endpoints. Both approaches contain sequence, period and treatment effects and subjects were nested in sequence as a repeated factor.

Furthermore, possible learning effects were analyzed by comparing the different periods (test A_1 and B_1 with test A_2 and B_2). Finally, tests with and without device were compared using the primary and secondary endpoints. The statistical model was powered to evaluate the isolated effect of the device excluding potential learning effects. The possible influence of covariables such as age, body mass index (BMI) and education was investigated by extending the model by one covariable at a time.

For a more detailed analysis of the device's effect on different outcomes within a certain group, an analysis by McNemar for binary outcomes and a paired *t*-test for continuous outcomes was applied.

Assessment of potential learning effects was performed by using Fisher's exact test for binary outcomes and unpaired *t*-test for continuous outcomes. Group A and B were therefore compared both with and without device.

All statistical tests were two-tailed. Due to the exploratory character of the study, no alpha-adjustment was performed. Thus, a *p*-value of <0.05 was considered to demonstrate statistical significance. All statistical analyses were carried out with SAS version 9.1.3 (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Study population

Out of 94 potential subjects, 93 (age 32 ± 7.2 (range 21–61) years; 72% male) were included (one subject excluded due to physical impairments). The resulting sample was composed of 34 EMS-physicians, 14 EMTs and 45 paramedics (demographic details Table 1). Thus, considering the anticipated drop-out rate of 10%, the calculated sample size was surpassed.

An investigation of the quality of the study design and the statistical approach did not result in any significant differences between the groups. Therefore, a potential carry-over effect is very unlikely.

3.2. Observed endpoints

3.2.1. Compression depth

Correct mean compression depth was achieved by 45.2% without the device vs. 73.1% with the device ($p < 0.001$). For both groups combined, the mean compression depth was 48.9 ± 4.3 mm (group A: 50 ± 3.9 mm; group B: 47.9 ± 4.5 mm) with feedback and 47.7 ± 8.8 mm (group A: 46.3 ± 7.7 mm; group B: 49.1 ± 9.5 mm) without feedback. Considering the 95%-confidence interval (95%-CI), there was a significant difference between compressions with

Table 1
Overview of study population and demographics.

Qualification	Group A		Group B		Overall	
	n	%	*n*	%	*N*	%
Emergency medical technician	9	19.6	5	10.6	14	15.1
Paramedic	19	41.2	26	55.3	45	48.4
Physician	18	39.1	16	34.0	34	36.6
Total	46		47		93	
Demographics						
Height (cm)	177.9 ± 9.2		177.9 ± 8.6			
Body weight (kg)	78.8 ± 16.9		79.6 ± 14.8			
Professional EMS-experience (years)	8 ± 5.9		6 ± 4.5			
	≤6 months	>6 months	≤6 months	>6 months		
Last CPR	30 (65.2%)	16 (34.8%)	37 (78.7%)	10 (21.3%)		
Last CPR training	22 (47.8%)	24 (52.2%)	20 (42.6%)	27 (57.4%)		

Table 2
Overall performance results with and without the feedback device.

	With feedback (*n* = 20025)		Without feedback (*n* = 21190)		*p*-Value
	n	%	*n*	%	
Correct compression depth	14086	70.3	9616	45.4	$p < 0.0001$
Too deep compressions	5541	27.7	8339	39.4	$p = 0.0452$
Too shallow compressions	398	2.0	3235	15.3	$p < 0.0001$
Compressions with inappropriate decompression	33	0.16	929	4.4	$p = 0.0075$
Correct compression depth > 80%	53	57.0	26	28.0	$p < 0.0001$
Too deep compressions > 20%	36	39.8	49	52.7	$p = 0.0349$
Too shallow compressions > 20%	2	2.0	17	18.3	(–)[a]
Inappropriate decompression >5%	0	0.0	12	12.9	(–)[a]
Correct compression rate	88	94.6	58	62.4	$p < 0.0001$
Faultless compressions[b] > 80%	50	53.8	22	23.7	$p < 0.0001$
Sufficient compressions[c] > 80%	48	51.6	17	18.3	$p < 0.0001$

Data are listed as *n* and as the percentage of each group.
[a] No statistical evaluation possible, at least one of the parameters was "0".
[b] Adequate compression depth and chest wall decompression.
[c] Adequate compression depth, decompression and rate.

(40.3–57.4 mm) and without feedback (30.5–64.9 mm), details Table 2.

3.2.2. Compression rate

With feedback system, 94.6% of subjects met required criteria. Only 5.4% performed ECC at a higher rate. In contrast, only 62.4% ($p < 0.0001$) of the resuscitation efforts were performed at correct rate without device. Twenty-nine percent of subjects compressed too fast; 8.9% compressed too slow.

Combining both groups, mean compression rate was $107 \pm 9.9\,\text{min}^{-1}$ (95%-CI: 87.3–126.6 min^{-1}; group A $105.9 \pm 7.6\,\text{min}^{-1}$; group B $108.1 \pm 11.9\,\text{min}^{-1}$) with feedback and $113.9 \pm 17.3\,\text{min}^{-1}$ (95%-CI: 78–147.8 min^{-1}: group A $110.9 \pm 13\,\text{min}^{-1}$; group B $116.8 \pm 20.4\,\text{min}^{-1}$) without device.

3.2.3. Quality of chest compressions

Without feedback, 4.4% of compressions had inadequate chest wall release, with device 0.16% ($p = 0.0075$). To evaluate a more relevant quality measure, the overall quality of ECC for each resuscitation effort was determined. Percentage of compressions in each category of depth error was recorded for each effort (too deep/shallow, inappropriate decompression). Greater than 20% too deep or shallow was considered inappropriate, but for decompression, a lower cut-off of 5% was used. Additionally, the two criteria of compression depth and decompression sufficiency were combined by recording the number of faultless compressions (appropriate depth and decompression). A percentage of at least 80% faultless compressions were considered to be sufficient. Overall, at least 80% faultless compressions was achieved by 53.8% with and 23.7% without feedback ($p < 0.0001$). Rate criteria were also examined. Subjects who had at least 80% faultless compressions and a rate of 90–120 min^{-1} were deemed to have performed sufficient compressions: with feedback 51.6%, without 18.3% of the subjects fulfilled these criteria ($p < 0.0001$).

3.2.4. Correlation with demographic data

In cross-over-analysis, a significant covariable effect on ECC performance was detected concerning the time since last CPR training:

Table 3
Learning effects between groups in the cross-over analysis.

Variable	Cross-over-analysis (comparing periods)	Group A (comparing A_1 to B_2)	Group B (comparing B_1 to A_2)
Compression rate	0.5378	0.0322	1.0000
Compression depth	0.0029	0.0971	0.0368
Compression depth (%)	0.0035	0.0494	0.0294
Compression sufficiency	0.0025	0.0645	0.0227

Variables: compression, compression depth, compression depth (%) and compression sufficiency.

If the last training session was less than 6 months prior ($n = 42$), subjects performed significantly better whether using the device or not (59.5% vs. 28.6%; $p = 0.0103$).

3.2.5. User satisfaction

Most of the participants stated that the device was helpful in applying correct ECC (85%; $n = 79$) while 18.3% ($n = 17$) felt that it was disruptive. Overall, 80.6% ($n = 75$) would use it regularly if available.

3.2.6. Fatigue effects

There was no significant difference in the mean fatigue value reported with (3.6 ± 1.8) or without (3.7 ± 2.1) device. About 44% of the subjects rated individual exhaustion as similar under both conditions, 25.8% felt less stressed with the device and 30.1% found themselves more fatigued after using it.

3.2.7. Learning effects

In cross-over analysis, significant differences were found in nearly all categories between first and second evaluation except for compression rate. Indeed, the data suggest that group A was influenced by prior use of the device in the second test ($p = 0.0322$) (Table 3).

4. Discussion

With increasing evidence for the importance of ECC, methods to support and improve rescuers' performance are gaining interest in recent research. Although different technical approaches have been evaluated,[6–8] no attempts have been made to invent simple devices as stand-alone solutions to improve ECC in healthcare professionals. This study evaluated a new visual feedback system intended as a stand-alone device for healthcare professionals and laypersons for use to aid ECC. Use of the device was associated with significant improvement in performance by healthcare professionals in terms of compression rate and depth as well as overall ECC sufficiency. Additionally, the device was able to be used by all subjects after short simple instructions, and most users were convinced of its simplicity and usability.

The first example of an ECC feedback system came in 1992, when Kern et al. demonstrated that ECC performance was improved by employing a simple metronome,[9] and a few years later Milander et al. concluded that audible tone guidance could lead to higher compression rates.[10] Increasing knowledge about quality deterioration during CPR as an effect of fatigue[11] has led to more efforts to develop strategies to prevent this effect and was pushed forward in different studies.[5,12–14]

The development of a 'stand-alone' system used by professionals as well as trained first responders seems to be a necessary next step to strengthen the initial links in the chain of survival in these settings. Although many devices to support CPR by different means were developed over the last decade, none have been implemented as a standard in patient care, and ECC is usually performed without any adjuncts either by laypersons or professionals.[15]

In 1998, the CPR-Plus was the first stand-alone support developed providing feedback only on compression depth and incomplete release, but could demonstrate a reduction in the number of incorrect compressions as well as an reduction in fatigue effects.[7]

The device CPREzy™ was described by Boyle et al. in a test with non-medical hospital staff ($n = 32$)[16] observing comparable results to our findings with significant improvement in compression rate and depth, especially during the last minute of CPR. These results were validated in a randomized controlled study with 202 laypersons,[6] with improvement in the same parameters as well as a learning effect regarding compression depth. Additionally, the CPREzy was evaluated in subjects with a higher level of training in a study that included 20 certified BLS/AED instructors[17]: They found a significant improvement in compression depth but a higher number of incorrect compressions using the device (mainly too shallow compressions), in contrast to our findings. Noordergraaf et al. reported data on varied hospital staff ranging from non-medical employees up to physicians with unspecified qualification levels.[8] In this non-cross-over study, they found that the number of adequate compressions in terms of consistent and adequate depth was increased significantly using CPREzy, but in contrast to our findings no improvements in compression rate were observed. Recently, van Berkom et al. published a study focusing on subjective evaluations of CPREzy users reporting that workload is increased[18]: they confirmed this hypothesis and detected between 21% and 26.5% greater work, but concluded that total work remains in "the manageable range" for rescuers and that improved compression depth resulting from use of this device was the most decisive factor for increased workload as well as rescuer fatigue.

Currently one study evaluated the newly developed PocketCPR™ (Zoll Medical, Chelmsford, MA, USA) in laypersons: Grassl et al. found merely significant improvement in only one of the study groups for compression depth and rate in simulated setting.[19] They postulated more studies to evaluate this device in healthcare professionals.

Our study confirmed the previous findings about professionals' weak performance on ECC previously mentioned. Notably, Wik et al. stated that such observed results cannot be explained by poor motivation,[20] as all of the tested subjects were involved in resuscitation attempts on a regular basis.

Previous manikin studies were able to demonstrate a correlation between force and compression depth and gender,[21] body height and weight[17,21] as well as professional experience[22]: female subjects achieved fewer compressions with adequate depth, and more professional experience leads to an increased amount of correct cardiac compressions, whereas no significant effects were detected regarding compression rate.[17,21] In the present study, the only significant correlation found was between the date of last CPR training and the sufficiency of CPR ($p = 0.0103$): subjects with CPR training more than 6 months prior had significantly worse performance with and without feedback. This effect was smaller with the device but still present, suggesting that a feedback system is not able to substitute for regular training sessions. This effect corresponds to findings in other studies, showing that theoretical knowledge lasts longer than adequate practical performance.[20,21]

An important factor influencing quality of CPR is the effect of fatigue, and animal studies have demonstrated a rapid decrease in adequate thoracic compressions after 1[23] and 2 min.[24] Even though the present study was not constructed to investigate objective parameters of user fatigue, subjective self-assessment by the subjects was recorded. Noordergraaf et al. reported that the CPREzy was able to lengthen the time until the quality of CPR decreases,[8] an effect that is probably transferable to the new feedback system. While about 20% more rescuer workload was reported for the CPREzy,[25] there is unlikely to be any additional physical effort required for the tested device because of the used accelerometer-technology in contrast to the spring-based CPREzy.

Overall, 80% of users found the new feedback device usable and acceptable, which is comparable to rates in laypersons with the CPREzy[6] and only 20% of subjects felt disturbed using the new device, whereas 95% of professional users reported wrist pain while using the CPREzy.[17]

This study is limited in that the gender ratio in the study group is not balanced (72% male), but this ratio is representative of healthcare professionals involved in emergency medical care. In addition, no manikin can perfectly mimic humans, especially when representing an unconscious, apnoeic and pulseless victim.

However, multiple studies have validated the use of manikins and methodologies have been well described,[7,12,16,20,26,27] but it is still debated whether findings in simulated cardiac arrest are applicable to clinical practice. Observations on compression depth suggest that healthcare professionals in reality generally compress too shallowly[3] but in simulated cardiac arrest scenarios tend to compress too deep.

Several other devices used as 'stand-alone' assistance to ECC have been developed and further will be forthcoming this year (e.g. feedback device from Laerdal Medical (Stavanger, Norway). There will be comparisons between various devices and discussions about efficacy and usability, and this manikin study provides a possible model for testing new devices used by healthcare providers.

5. Conclusions

The new visual feedback device described here is able to significantly improve performance of ECC by professional healthcare workers in simulated cardiac arrest in terms of compression rate and depth as well as overall ECC sufficiency. Additionally, most users found this device to be simple and usable.

These results show that use of this 'stand-alone' system by professionals and trained first responders is feasible and may be useful to strengthen the second link in the chain of survival. Using such devices in resuscitation routines may be an important step to improve outcomes in cardiac arrest. Overall, we can assume that multimodal strategies are needed to initiate real-time reflection by healthcare professionals during CPR and that the development and implementation of an optimal system will continue.

Conflict of interest statement

The authors declare that they have no competing interests. The device was supported during the study by Laerdal Medical, Munich, Germany. Laerdal Medical did not review or revise the manuscript at any stage of preparation.

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