Simulation and education

Comparing three CPR feedback devices and standard BLS in a single rescuer scenario: A randomised simulation study

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ABSTRACT

Background: Efficiently performed basic life support (BLS) after cardiac arrest is proven to be effective. However, cardiopulmonary resuscitation (CPR) is strenuous and rescuers’ performance declines rapidly over time. Audio-visual feedback devices reporting CPR quality may prevent this decline. We aimed to investigate the effect of various CPR feedback devices on CPR quality.

Methods: In this open, prospective, randomised, controlled trial we compared three CPR feedback devices (PocketCPR®, CPRMeter®, iPhone app PocketCPR®) with standard BLS without feedback in a simulated scenario. 240 trained medical students performed single rescuer BLS on a manikin for 8 min. Effective compression (compressions with correct depth, pressure point and sufficient decompression) as well as compression rate, flow time fraction and ventilation parameters were compared between the four groups.

Results: Study participants using the PocketCPR® performed 17 ± 19% effective compressions compared to 32 ± 28% with CPRMeter®, 25 ± 27% with the iPhone app PocketCPR®, and 35 ± 30% applying standard BLS (PocketCPR® vs. CPRMeter® p = 0.007, PocketCPR® vs. standard BLS p = 0.001; others: ns). PocketCPR® and CPRMeter® prevented a decline in effective compression over time, but overall performance in the PocketCPR® group was considerably inferior to standard BLS. Compression depth and rate were within the range recommended in the guidelines in all groups.

Conclusion: While we found differences between the investigated CPR feedback devices, overall BLS quality was suboptimal in all groups. Surprisingly, effective compression was not improved by any CPR feedback device compared to standard BLS. All feedback devices caused substantial delay in starting CPR, which may worsen outcome.

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1. Introduction

Cardiac events are a leading cause of death worldwide, despite our best life support efforts, and outcome after cardiac arrest is still poor.1−3 Several investigations strongly suggest that efficiently performed basic life support (BLS) is the only sufficient and immediately available treatment for cardiac arrest and may improve long term outcome.14 However, rescuers’ cardiopulmonary resuscitation (CPR) performance – particularly external chest compression quality – decreases rapidly over time.5 Thus a number of devices providing audio-visual feedback during chest compressions (CPR feedback devices) have been introduced in an effort to improve BLS quality.2,4,6−7 Such CPR feedback devices can be used by medical staff and trained laypersons alike even if manual defibrillators or automated external defibrillators (AED) are not available, or defibrillators without CPR feedback are used.8−10


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These devices seek to become a clinical standard, but at present, data on the improvement of resuscitation quality using such devices are insufficient, and no direct comparison of such CPR feedback devices has been performed. Because of the lack of performance data, we compared three CPR feedback devices (Zoll PocketCPR®; Laerdal CPRmeter®, iPhone app Zoll PocketCPR®) with standard BLS without feedback in a simulated single-rescuer BLS without a defibrillator in an 8-minute scenario. In a previous study on CPR feedback devices integrated into an AED we showed an improvement in effective compression of about 15% compared to standard BLS.6 The aim of our current study was to investigate whether standalone CPR feedback devices improve CPR quality compared to standard BLS.

Therefore, our 0-hypothesis was that CPR feedback devices would not improve chest compression efficiency compared to standard BLS in a group of trained lay rescuers over time.

2. Materials and methods

2.1. Study protocol

This open, prospective, randomized, controlled parallel group study was approved by the Ethics Committee of the Medical University of Vienna (EK No. 1676/2012). Over a period of four weeks, we recruited 240 medical students at the compulsory BLS course in their fifth semester of medical school. Exclusion criteria were upper extremity injuries, pregnancy. All study participants received standardized BLS training prior to the investigation. It was communicated to the study participants that their participation would not influence their grades for the BLS course.

After written informed consent, the medical students were randomized in four groups of 60 study participants using a block randomization list from a randomizer (https://www.meduniwien.ac.at/randomizer/web/login.php). Sealed envelopes containing the randomization number and group allocation were prepared to be opened by a member of the investigative team as the subjects entered the study facilities immediately prior to testing.

Prior to the study measurements, all participants were familiarized with the three CPR feedback devices and standard BLS without feedback using a modified 4-stage approach, where the first stage consisted of a 10-minute video presentation. In the final stage, participants practised CPR according to their randomized CPR feedback device or standard BLS under supervision until they declared that they felt sufficiently trained. After completion of training, participants performed 8 min of single-rescuer CPR with mouth-to-mouth ventilation according to the ERC 2010 guidelines. This time span without a change in rescuer was chosen to investigate the effect of feedback devices on the CPR quality over time as investigated earlier. The investigated devices have never been studied in such a scenario of prolonged single rescuer resuscitation.

The CPR feedback device groups performed resuscitation according to the prompts given by their CPR feedback device; the standard BLS group got neither prompts nor metronome guidance on performing CPR. The manikins were placed on a firm and even floor in a dry room to avoid an inaccurate measurement of compression depth on a soft surface.

For the CPR quality measurements we used two Ambu®ManC manikins (Ambu, Ballerup, Denmark) with medium thorax resistance that were connected to two identical personal computers (Fujitsu Siemens, Amilo PA 1510) for data recording and analysis. As previously, we measured CPR quality with Ambu® CPR Software (version 2.3.9, Ambu®, Ballerup, Denmark) and extracted the recorded data to a Visual Basic based excel macro (Microsoft Excel 2003, Microsoft Visual Basic 6.3, Microsoft Corporation, Redmond, WA, USA). The accuracy of manikins and software measurements was assessed prior to the start of the study using Thumper® model 1005 (Michigan Instruments Inc., Grand Rapids, MI), which was set to various compression depths between 1 and 6.3 cm (maximum compression depth of our manikins).

2.2. CPR feedback devices

(a) The Zoll PocketCPR® (Zoll Medical, Chelmsford, USA) is a small, battery powered CPR feedback device that is placed beneath the hands of the rescuer on the victim’s sternum. Compression rate and depth are measured by an integrated accelerometer. Apart from a metronome, it provides acoustic and visual feedback about corrections to be made on compression rate and depth during CPR.

(b) The Laerdal CPRmeter® (Laerdal, Stavanger, Norway) is used similarly to PocketCPR®, but data are obtained through an accelerometer and a pressure sensor. It provides visual feedback on compression rate, depth and decompression during CPR.

(c) The iPhone app Zoll PocketCPR® (Zoll Medical, Chelmsford, USA) is an application available for iPhones. The phone is strapped to the back of the rescuer’s hand with an iPhone strap; we used a Griffin Adidas® MiCoach armband for the iPhone 4G (Adidas, Germany). Data are obtained via the integrated accelerometer of the iPhone, and the app provides feedback equal to the Zoll PocketCPR® device. This app had not been investigated prior to our study.

2.3. Measurements and outcomes

Our primary outcome was the previously published compound parameter effective compression (EC) expressing the most relevant measurements of chest compression quality in a single figure. According to the ERC 2010 guidelines, EC was defined as compressions performed with the correct depth (50–60 mm), the correct hand position and complete decompression. Complete decompression was defined as no residual leaning of more than 10 mm in accordance with previous studies to eliminate artifacts due to the high sensitivity of the manikin.

In addition, we recorded as secondary outcomes: effective-compression-ratio (ECR: effective compression [%] multiplied by flow time fraction [%]), compression depth and rate, incomplete decompression and incorrect hand position, and injuries to the study participants by the devices. Further measured secondary outcomes were flow time fraction (time fraction with chest compressions), absolute hands-off-time (HOT): time fraction without chest compressions or ventilations), time from device activation to first performed chest compression, as well as the ventilation parameters tidal volume, minute volume and gastric inflations. The obtained measurements for each participant were averaged, and the results were averaged again for each group to obtain one single value per group to compare.

2.4. Subjective assessment by study participants

After having completed the 8 min testing period, the study participants were asked how challenging they had experienced standard BLS or resuscitation with the respective feedback device. Answers were rated on a 10-point Likert scale (most difficult = 1 to easiest = 10). Additionally, they were asked which method they would prefer, given a real-life resuscitation.

2.5. Statistical analyses

Based on previous investigations, we assumed a mean difference of 15% effective compression with a standard deviation of 18% between feedback devices and standard BLS as clinically relevant. Hence, based on a two-sided t-test with alpha = 0.0083 (Bonferroni corrected for all pairwise comparisons between the four groups) and a power of 80%, a sample size of 37 study participants per group was needed. To adjust for possible dropouts, the group size was adapted to 60 study participants, resulting in an overall sample size of 240 study participants included in the study.

The number of EC performed in 8 min of CPR was analyzed in time intervals of 15 s.21 We compared the four groups using x² tests for nominal data and analysis of variance (ANOVA) with post hoc comparisons using the Bonferroni correction for metric variables. We used the Kruskal–Wallis test to compare not normally distributed parameters. Measurements over time (EC, ECR, compression depth, compression rate, incomplete decompressions, incorrect pressure point, minute volume, ventilation volume, device placement to first compression, injuries) were compared between the four groups using linear mixed effects models with the study participants being the random variable. As a sensitivity analysis, the two Ambu®ManC manikins are compared by an unpaired Student's t-test.

Results are stated as mean±SD or median and IQR for frequencies and percentages. P-values <0.05 were considered as statistically significant.

SPSS 21 for Mac and R 2.1.12 (R Foundation for Statistical Computing, R development core team, Vienna, Austria) were used for the analyses.

3. Results

Out of 244 potential study participants, one was ineligible for our investigation due to pregnancy and three due to previous musculoskeletal upper extremity injuries (Fig. 1). Demographic characteristics of the 240 study participants in the 4 study groups are shown in Table 1. No dropouts occurred after randomization. There was no significant difference in real life CPR experience and resuscitation training between the groups. The mean time of the study participants’ training, until they felt competent to start the study, was significantly prolonged in all CPR feedback device groups compared to standard BLS (p < 0.001).

Differences in the sensitivity of the two manikins were negligible and clinically irrelevant. Mean difference between set compression depth and compression depth measured by the manikin software was 1±0.1 mm and differed by 0.2 mm between the two manikins.

One participant had to abandon the test after 7 min and 30 s due to an injury from a CPR feedback device (CPRmeter®) but was not excluded from analyses.

3.1. Compression parameters

Chest compression with the PocketCPR® resulted in 17 ±19% ECRs, in 32 ±28% ECRs with the CPRmeter®, EC was 25 ±27% using the iPhone app, and in 35 ±30% ECRs in the standard BLS group (PocketCPR® vs. CPRmeter® p = 0.007, PocketCPR® vs. standard BLS p = 0.001, all other comparisons: ns; Table 2).

3.2. Effective compressions over time

The EC increased per minute by 9% with the use of the PocketCPR®, 5% with the CPRmeter®, but decreased by 3% with the iPhone app, and 1% with standard BLS (p < 0.001 for PocketCPR® vs. standard BLS, all others: ns; Fig. 2).

Mean compression depth and compression rate were within the recommended range in all groups. Incorrect decompressions after chest compressions were significantly increased in the PocketCPR® group compared to CPRmeter® (p < 0.001) and standard BLS (p < 0.001).

Chest compressions were performed on an incorrect compression point in 1 (0–11%) in the PocketCPR® group, which is significantly more than in the CPRmeter® (p < 0.001) and standard BLS group (p = 0.002). Injuries (blisters on the subject’s palms) occurred in all groups (Table 2).

3.3. Time related parameters

Flow time fraction was minimally increased over time with the PocketCPR® and the iPhone app compared to standard BLS (p = 0.015 and p < 0.001 respectively). There was no significant

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Baseline characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PocketCPR® (n=60)</td>
</tr>
<tr>
<td>Sex (female), n/%</td>
<td>21/35</td>
</tr>
<tr>
<td>BMI®</td>
<td>23 ± 3</td>
</tr>
<tr>
<td>Age [years]</td>
<td>72.1 ± 2</td>
</tr>
<tr>
<td>Real patient resuscitation performed, n/%</td>
<td>15/25</td>
</tr>
<tr>
<td>Months since last resuscitation</td>
<td>17 ± 13</td>
</tr>
<tr>
<td>Last BLS course within n/%</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
</tr>
<tr>
<td>&lt;6 months ago</td>
<td>47/78</td>
</tr>
<tr>
<td>6–12 months ago</td>
<td>0</td>
</tr>
<tr>
<td>12–24 months ago</td>
<td>7/12</td>
</tr>
<tr>
<td>&gt;24 months ago</td>
<td>5/9</td>
</tr>
<tr>
<td>Missing</td>
<td>1</td>
</tr>
<tr>
<td>Duration of training until competent [s]</td>
<td>95 ± 55</td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation.

* Body mass index: weight [kg]/height [m²].

* ANOVA’s overall p-values are given.

* ANOVA’s Bonferroni corrected p-values are given.

The difference between CPRmeter® and standard BLS. Absolute-HOT was significantly decreased by the iPhone app compared to standard BLS. Time from device activation to first chest compression in the CPR feedback device groups and time from the beginning of measurement to first chest compression in the standard BLS group differed significantly among all groups with standard BLS being the fastest (Table 2).

### 3.4 Ventilation parameters

Ventilation parameters were not significantly different between the observed groups. Significantly more gastric inflations occurred in the group using the iPhone app compared to standard BLS (p = 0.013, Table 2).

### 3.5 Subjective assessment

Participants’ subjective assessment of resuscitation with the CPR feedback device or standard BLS showed no significant difference between the groups. Concerning preferences in hypothetical real life resuscitation, 45% voted for standard BLS without feedback vs. 53% for resuscitation with a CPR feedback device (2% missing). There was no significant difference between the four groups (p = 0.376).

### 4. Discussion

This study investigated the efficiency of chest compressions comparing three CPR feedback devices (Zoll PocketCPR®, Laerdal CPRmeter®, the iPhone app Zoll PocketCPR®) and standard BLS without feedback in a simulated setting. We confirmed our hypothesis that chest compression efficiency did not improve through the application of any of the standalone CPR feedback devices compared to standard BLS.

The effective compression (EC), a compound parameter to easily compare chest compression quality, was not improved by using any CPR feedback device compared to standard BLS without feedback. Our finding contrasts results of previous investigations that found improved CPR quality through CPR feedback devices compared to standard BLS. These discrepancies may be due to the expanded analysis of quality markers for chest compression in our study, while previous authors primarily focused on compression depth and/or compression rate.

Our analysis shows considerable room for improvement since only 35 ± 30% of compressions were efficient in the best group – the standard BLS providers. The measured ECR also were considerably below the target value of 0.79 in all groups. Both EC and ECR were comparable to similar investigations with a wide range for ECR from 0.03 to 0.67 among previously published studies.

That means, on one hand, much more teaching is necessary to improve BLS performance, even for professional providers. Since standard BLS was not very efficient, we expected the investigated feedback devices to improve CPR performance substantially to a clinically acceptable range, which might be at least more than an ECR of 50%. That was not achieved by these types of CPR feedback devices; none performed better than standard BLS. One possible explanation is that none of these devices have a built-in reference to evaluate whether chest compressions are effective. Specifically,

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The figure below illustrates the Consort trial flow chart.
Table 2
Compression, ventilation and time related related parameters.

<table>
<thead>
<tr>
<th></th>
<th>PocketCPR® (n=60)</th>
<th>CPRmeter® (n=60)</th>
<th>iPhone app® (n=60)</th>
<th>Standard BLS (n=60)</th>
<th>p-Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest compression parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective compression %b</td>
<td>17 ± 19</td>
<td>32 ± 28</td>
<td>25 ± 27</td>
<td>35 ± 30</td>
<td></td>
</tr>
<tr>
<td>Effective compression ratio (ECR)c</td>
<td>0.12 ± 0.14</td>
<td>0.23 ± 0.20</td>
<td>0.18 ± 0.20</td>
<td>0.25 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>Compression depth [mm]</td>
<td>58 ± 5</td>
<td>59 ± 3</td>
<td>59 ± 4</td>
<td>55 ± 7</td>
<td></td>
</tr>
<tr>
<td>Compression rate [min⁻¹]</td>
<td>105 ± 10</td>
<td>112 ± 8</td>
<td>107 ± 4</td>
<td>113 ± 12</td>
<td></td>
</tr>
<tr>
<td>Incorrect decompressions %</td>
<td>40 ± 34</td>
<td>19 ± 22</td>
<td>26 ± 32</td>
<td>17 ± 28</td>
<td></td>
</tr>
<tr>
<td>Incorrect pressure point %</td>
<td>1 (0–11)</td>
<td>0 (0–0)</td>
<td>0 (0–3)</td>
<td>0 (0–0)</td>
<td></td>
</tr>
<tr>
<td>Injuries, m²/d³</td>
<td>8/13</td>
<td>7/12</td>
<td>7/12</td>
<td>2/3</td>
<td>ns</td>
</tr>
<tr>
<td>Time related parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow time fraction %e</td>
<td>72 ± 5</td>
<td>71 ± 4</td>
<td>74 ± 5</td>
<td>70 ± 4</td>
<td></td>
</tr>
<tr>
<td>Flow time/min [s]f</td>
<td>44 ± 3</td>
<td>43 ± 3</td>
<td>45 ± 3</td>
<td>42 ± 3</td>
<td></td>
</tr>
<tr>
<td>Absolute hands-off time [s]g</td>
<td>99 ± 30</td>
<td>99 ± 24</td>
<td>88 ± 25</td>
<td>103 ± 30</td>
<td></td>
</tr>
<tr>
<td>Time till first chest compression [s]h</td>
<td>15 (5–24)</td>
<td>5 (3–10)</td>
<td>6 (5–12)</td>
<td>0 (0–2)</td>
<td></td>
</tr>
<tr>
<td>Ventilation parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minute volume [ml/min]</td>
<td>1689 ± 1073</td>
<td>2171 ± 1329</td>
<td>1700 ± 1178</td>
<td>2248 ± 1327</td>
<td>ns</td>
</tr>
<tr>
<td>Ventilation volume [ml]</td>
<td>542 ± 261</td>
<td>508 ± 267</td>
<td>531 ± 258</td>
<td>509 ± 288</td>
<td>ns</td>
</tr>
<tr>
<td>Ventilation time/min [s]</td>
<td>4 ± 2</td>
<td>5 ± 2</td>
<td>4 ± 2</td>
<td>5 ± 3</td>
<td>ns</td>
</tr>
<tr>
<td>Gastric inflations, n</td>
<td>0 (0–6)</td>
<td>0 (0–2)</td>
<td>0 (0–15)</td>
<td>0 (0–1)</td>
<td></td>
</tr>
</tbody>
</table>

Normally distributed data are presented as mean ± standard deviation; data not following normal distribution are presented as median (IQR).

* Bonferroni corrected p-values are given.

b Effective compression was defined as compression with correct depth (50–60 mm), correct hand position, and complete decompression.

c Effective compression ratio was defined as effective compression [%] multiplied by flow time [s].

d Observed injuries were: blisters.

e Flow time was defined as the sum of all periods during which chest compressions were performed.

f Absolute hands-off time (HOT) was defined as the sum of all periods without chest compression or ventilation.

g Time till first compression was defined as time from device activation to first chest compression in the CPR feedback device groups and time from beginning of measurement to first chest compression in the standard BLS group.

We found an incorrect compression point is not corrected with the devices. Such feedback about the efficiency of the applied chest compression would be much more valuable for the provider. Surprisingly, the use of the PocketCPR® resulted in significantly less EC and ECR compared to CPRmeter® and to standard BLS. A high percentage of insufficient decompressions and compressions with incorrect compression points with the use of the PocketCPR® seem to be the reason for that finding. The relatively high incidence of 40 ± 34% incorrect decompressions using the PocketCPR® might be explained by the fact that the device operates without a

Therefore, in One in 6 B. flow-time PocketCPR Increased and (2) ties subjective impairing RESUS-5777; to Absolute-HOT Model randomised Please Yannopolous Chest Surprisingly standard Compression with recommendations cannot the feedback increased iPhone cite previous devices, which is consistent with previous findings. Increased flow time fraction and decreased absolute-HOT might be beneficial for CPR outcome. One reason for the better performance of the PocketCPR® and iPhone app devices might be the devices’ voice prompts during the feedback process.

One downside of all tested CPR feedback devices that is often overlooked was the significant increase in time from the start of the measurement (the time CPR, e.g. chest compression, should have been started) to the recorded first chest compression compared to standard BLS. That latency annihilates the observed reduction of absolute-HOT through CPR-feedback devices, especially in the critical minutes directly after cardiac arrest occurs. Increased absolute-HOT directly negatively affect hemodynamic parameters and outcome.

EC improved significantly (for the PocketCPR® and CPRmeter®) over time compared to standard BLS, whose EC declined only minimally during 8 min of resuscitation. However, overall CPR quality in the PocketCPR® group was clearly below standard BLS at all times and especially poor at the start of CPR. Since the performance of the PocketCPR® was inferior overall compared to standard BLS, we doubt that the statistical improvement over time for that device is of any clinical relevance.

4.1. Limitations and strengths of the study

As in all studies of simulated cardiac arrest, the conditions only reflect those of real life scenarios to a limited extent. Interpretation of gastric inflations and injuries (e.g. blisters) proves difficult since our investigation was designed to assess our primary outcome, the EC, and was therefore insufficient to analyze such infrequent events, as they were not the main focus.


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Fig. 2. Effective compression (A) and incomplete decompression (B) over time.
Our study population consisted of recently trained BLS providers; a greater impact of CPR feedback devices on BLS quality may be possible in a group of rescuers with insufficient or outdated training.

The participants in the standard BLS group trained significantly shorter to feel sufficiently trained before beginning the investigation. Since all groups had undergone several hours of CPR training without feedback before, this seems only natural. Since no superior performance of the CPR feedback devices over standard BLS was observed despite the longer training, this does not constitute a bias in our investigation.

One of our study’s strong points is the thorough assessment of measurement accuracy of our manikins through Thumper and the local Ambu distributor and therefore the exclusion of relevant differences between the manikins. We performed a standardized method of teaching the study participants, and performed profound analysis of CPR quality through EC, while investigations by previous authors focused on compression depth and rate.

5. Conclusion

Despite several differences between the CPR feedback devices and standard BLS, none of the devices achieved an improvement in EC or ECR as markers for chest compression quality compared to standard BLS without feedback. CPR quality with the PocketCPR® was even significantly reduced due to insufficient decompression and incorrect compression point.

All CPR feedback devices caused delay in CPR start and may worsen outcome. PocketCPR® was the only device that significantly improved chest compression quality over time; however the device’s performance remained inferior to standard BLS at all times.

The performance of further improved CPR feedback devices needs to be thoroughly investigated.

Conflict of interest statement

None of the authors has a conflict of interest. The Laerdal CPRmeter® was provided by Laerdal free of charge during the period of the study. Apart from this, only departmental support was used for the study. Neither Zoll Medical nor Laerdal reviewed or revised the manuscript at any stage.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2013.10.028.

References