Improving Cardiopulmonary Resuscitation With a CPR Feedback Device and Refresher Simulations (CPR CARES Study) A Randomized Clinical Trial

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IMPORTANCE The quality of cardiopulmonary resuscitation (CPR) affects hemodynamics, survival, and neurological outcomes following pediatric cardiopulmonary arrest (CPA). Most health care professionals fail to perform CPR within established American Heart Association guidelines.

OBJECTIVE To determine whether “just-in-time” (JIT) CPR training with visual feedback (VisF) before CPA or real-time VisF during CPA improves the quality of chest compressions (CCs) during simulated CPA.

DESIGN, SETTING, AND PARTICIPANTS Prospective, randomized, 2 × 2 factorial-design trial with explicit methods (July 1, 2012, to April 15, 2014) at 10 International Network for Simulation-Based Pediatric Innovation, Research, & Education (INSPIRE) institutions running a standardized simulated CPA scenario, including 324 CPR-certified health care professionals assigned to 3-person resuscitation teams (108 teams).

INTERVENTIONS Each team was randomized to 1 of 4 permutations, including JIT training vs no JIT training before CPA and real-time VisF vs no real-time VisF during simulated CPA.

MAIN OUTCOMES AND MEASURES The proportion of CCs with depth exceeding 50 mm, the proportion of CPR time with a CC rate of 100 to 120 per minute, and CC fraction (percentage CPR time) during simulated CPA.

RESULTS The quality of CPR was poor in the control group, with 12.7% (95% CI, 5.2%-20.1%) mean depth compliance and 271% (95% CI, 14.2%-40.1%) mean rate compliance. JIT training compared with no JIT training improved depth compliance by 19.9% (95% CI, 11.1%-28.7%; P < .001) and rate compliance by 12.0% (95% CI, 0.8%-23.2%; P = .037). Visual feedback compared with no VisF improved depth compliance by 15.4% (95% CI, 6.6%-24.2%; P < .001) and rate compliance by 40.1% (95% CI, 28.8%-51.3%; P < .001). Neither intervention had a statistically significant effect on CC fraction, which was excellent (>89.0%) in all groups. Combining both interventions showed the highest compliance with American Heart Association guidelines but was not significantly better than either intervention in isolation.

CONCLUSIONS AND RELEVANCE The quality of CPR provided by health care professionals is poor. Using novel and practical technology, JIT training before CPA or real-time VisF during CPA, alone or in combination, improves compliance with American Heart Association guidelines for CPR that are associated with better outcomes.

TRIAL REGISTRATION clinicaltrials.gov Identifier: NCT02075450

E
cach year, cardiopulmonary resuscitation (CPR) is pro-
vided for thousands of children in North America.1-2 The
quality of CPR directly affects hemodynamics, sur-
vival, and neurological outcomes following cardiopulmo-
nary arrest (CPA).3-9 Unfortunately, health care professionals
struggle to retain effective chest compression (CC) skills after
basic life support or advanced cardiac life support training.10-12
Even well-trained health care professionals fail to consist-
ently perform CPR within established American Heart Asso-
ciation (AHA) guidelines during CPA.8,13-17

Video-based instruction can be just as or more effective than
traditional life support courses to teach CPR skills.16-21 In these
studies, learners watched an educational video and were given
opportunity to practice but did not receive feedback on the qual-
ity of CPR, and the training was not “just-in-time” (JIT). The JIT
bedside CPR practice with audiovisual feedback (but without
a video component) targeted to health care professionals with
a high likelihood of needing to deliver in-hospital CPR was found
to improve compliance with AHA CPR-quality guidelines on
manikins and real children during CPA.25-28 What is unknown
is whether JIT CPR visual feedback (VisF) training with video-
based instruction before CPA or real-time VisF during CPR, alone
or in combination, is effective in improving CPR quality.

The CPR feedback devices provide visual or auditory feed-
back based on quantitative CPR metrics during CPA and have
been shown to improve the quality of CCs when used during training29 and during real CPA events.6,30 Although these de-
vices show potential, no randomized clinical studies to date have evaluated the training method for using CPR-quality VisF
devices in CPA. Furthermore, multicenter clinical trials to as-
sume the effect of JIT CPR VisF training before CPA or real-
time VisF during simulated or real in-hospital CPA have not
been performed to our knowledge.

In this study, we evaluated a novel JIT CPR training inter-
vention that includes a video-based learning component and a
practical credit card–sized CPR VisF device. We also evaluated
the use of the CPR VisF device during simulated CPA. The VisF
device captures and displays depth and rate of CCs during CPR
practice and CPA. We used explicit methods to deploy a stan-
dardized simulated CPA scenario, carefully trained and scripted
conferederate actors, and captured quantitative CPR data across
10 International Network for Simulation-Based Pediatric Inno-
vation, Research, & Education (INSPIRE) institutions to describe
the quality of CPR. The primary objective was to determine
whether the use of JIT CPR training with VisF before CPA or real-
time VisF during simulated CPA improves the quality of CPR.

Methods

Research ethics board approval was obtained at all sites. Writ-
ten informed consent was obtained from all participants. We
conducted a multicenter, prospective, randomized, clinical
2 × 2 factorial-design trial with explicit simulation-based re-
search methods31 to assess the quality of CCs performed during
simulated CPA. Our 2 interventions were (1) JIT standard-
ized, brief CPR training with video and VisF before simulated
CPA and (2) real-time VisF during simulated CPA.

Study Participants

Inclusion and exclusion criteria are described in the eMethods
in the Supplement. Participants were recruited from 10 ter-

tiary care centers (eTable 1 in the Supplement) into teams of
3, with one individual preassigned to the role of team leader
to oversee the resuscitation efforts and 2 others assigned as
team members expected to perform CCs. Participants in-
cluded medical students, resident and fellow physicians,
nurses and nurse practitioners.

Interventions

VisF Device

A prototype practical, CPR-quality VisF device (CPRcard; Laer-
dal Corporation) measuring the size of a credit card (55 × 85 × 1
mm) and placed on the middle of the chest uses accelerom-
technology to record and display depth and rate of CCs
e(Figure 1 in the Supplement). The device provides real-time
VisF via light-emitting diodes for CC depth and rate. The CC
rate is indicated by a set of 3 light-emitting diodes set at rates
of less than 100, 100 to 120, and greater than 120 compres-
sions per minute, while compression depth is indicated by
separate lights set at depths of less than 40 mm (inadequate),
40 to 50 mm (infant), 50 to 70 mm (child or adult on a hard
surface), and greater than 70 mm (child or adult on a soft
surface). The CPRcard has undergone verification testing using
a mechanical device subjecting it to controlled horizontal
movements (with accurate depth and rate measurement),
which demonstrated variation between −5.9% and 1.4% of tar-
get depth and ±3 compressions per minute of target rate
(J. Eilledge, Laerdal Corporation, e-mail communication,
August 28, 2014).

JIT CPR VisF Training Before CPA

The JIT CPR training comprised the following 2 components:
a 5-minute standardized CPR training video, followed by 2 min-
utes of practice (per team member) with VisF on depth and rate
of CCs during practice (eMethods in the Supplement). Those
participants randomized to the no-JIT CPR training study arms
did not watch the video but practiced CPR for 2 minutes with
no VisF.

Outcome Measures

Data were collected from the VisF device, including CC depth,
CC rate, and CC fraction (CCF) averaged over the entire 12-
minute duration of the simulated CPA event.

Primary Outcome Measure

The primary outcome measure was CC depth. The propor-
tion of CCs during each 12-minute simulated CPA with depth
exceeding 50 mm was measured.32

Secondary Outcome Measures

Secondary outcome measures were CC rate and CCF. The pro-
portion of time that the CC rate met AHA guidelines (100-120
per minute)32 was calculated by the rolling median of the last
5 CC measurements in a series. The proportion of CPA time with
CC delivery was calculated as the time during CPA with CC de-

delivery divided by the total arrest time.32,33

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Improving CPR With a CPR Feedback Device

**Randomization**
Each team was randomized into 1 of the following 4 study arms: (1) no JIT CPR VisF training before CPA and no real-time VisF during CPA (control), (2) no JIT CPR VisF training before CPA and real-time VisF during CPA, (3) JIT CPR VisF training before CPA and no real-time VisF during CPA, and (4) JIT CPR VisF training before CPA and real-time VisF during CPA (Figure 1). No participant was a member of more than 1 team. Randomization occurred at the level of the team, was stratified by study site, and was conducted in blocks of 4 to ensure equal numbers of teams and participants across the study arms (eMethods in the Supplement).

**Standardized Simulated Scenarios, Confederate Actors, and the Simulation Environment**
After randomization, all participants were given a standardized video orientation to the research study, followed by (1) 2 minutes of CPR practice for each team member, with or without JIT CPR training; (2) a pediatric septic shock simulation scenario; and (3) a pediatric simulated CPA scenario (Table 2 and eFigure 2 in the Supplement). We standardized all elements of the simulation across sites and verified this by video review to minimize the simulation-specific threats to internal validity.34 All recruitment sites used an identical pediatric manikin (SimJunior; Laerdal Corporation) specifically designed and calibrated for CPR training (spring constant, 4.46 kg/cm; 22.3 kg of force required to press to 5 cm; and maximum compression depth of 7 cm). A 15-minute standardized septic shock scenario was conducted for all participants to minimize the Hawthorne effect of being videotaped, orient the team to the simulation environment, and draw attention away from CPR. The sepsis scenario was followed by a 10-minute debriefing with a focus on aspects of clinical care and teamwork (with no discussion of CPR). Next, a standardized 12-minute pediatric CPA scenario was conducted to collect data, depicting a 5-year-old child with pulseless electrical activity progressing to ventricular fibrillation. The VisF device was secured to the center of the manikin’s chest, but in study arms 1 and 3, the light-emitting diode lights were covered so that participants did not receive VisF during CPR. To ensure standardized delivery of the scenario, a preprogrammed scenario and a detailed scenario script were used at all sites (eMethods in the Supplement). Confederate actors were trained in a standardized fashion (eMethods in the Supplement) to play scripted roles of respiratory therapist and medication nurse, both of whom were instructed not to perform CPR. We standardized the equipment and the location of the defibrillator and medication cart across sites. The simulator was placed on a hard stretcher with no mattress to eliminate mattress compressibility as a confounding variable.34 We verified compliance with this method by (1) centralized review of one prestudy pilot session from each institution and (2) centralized review of all study videotapes (eMethods in the Supplement).

**Sample Size**
The sample size calculation assumed that the main effects of the 2 different interventions on the proportion of CC depth meeting AHA standards would comprise the 2 primary comparisons. Hence, allowing for Bonferroni adjustment, $P \leq .025$ was considered statistically significant for each of these 2 comparisons. For the sample size calculation, additivity of the intervention effects was assumed, with a plan to check this assumption in the analysis. The proportion of CEs meeting AHA standards for depth among health care professionals deprived of CPR feedback and JIT CPR training (control) has been reported to be approximately 60%, with an SD of approximately 25%.46 Assuming similar variability among teams receiving either intervention to detect a 15% difference in CEs meeting AHA standards for
depth between the control team and the teams receiving each of the interventions with 80% power at $\alpha = .025$ for each of the 2 primary comparisons, the required sample size would be 108 teams (27 per study arm). Based on prior experience with multicenter, simulation-based research, we estimated that 15% of the groups would be excluded owing to technical issues with data acquisition (16 teams), so we aimed to recruit 124 teams in total (31 per study arm).

**Statistical Analysis**

All data analyses were performed using statistical software (SPSS Statistics 21; IBM Corporation). Using team CC performance as the unit of measure, CPR event summaries of CC depth, CC rate, and CCF were calculated for each of 4 study arms. We used multivariable linear regression analysis to assess the effects of JIT CPR training or VisF on the primary and secondary outcome measures by including 2 intervention variables (JIT CPR training and VisF) and the interaction term (JIT CPR training $\times$ VisF) in the model. Recognizing that the effects could be nonadditive (whether or not the interaction test is statistically significant), we also report on the effect of each intervention at each level of the other intervention. All estimates of intervention effects are reported as differences in means and 95% CIs, with no adjustment for multiple comparisons.

**Results**

**Study Population**

In total, 124 teams (372 participants) were recruited from July 1, 2012, to April 15, 2014. Sixteen teams (48 participants) were excluded from the study because of technical issues (eg, the VisF device was not turned on at the appropriate time, or the VisF device was inadvertently shut off part way through the scenario [13 teams, 39 participants]) or because of a violation of the study protocol (eg, a mattress was used during simulated CPA [3 teams, 9 participants]). Data from the remaining 108 teams (324 participants) were included in the analysis (Figure 1). No significant difference was found in the demographic characteristics of the participants between the study arms at baseline (Table 1). The results were not significantly different in a sensitivity analysis that adjusted for clustering within centers.

### Table 1. Demographic Characteristics of Participants in the Study Arms

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arm 1: No JIT and No VisF (n = 81)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>24 (29.6)</td>
</tr>
<tr>
<td>Female</td>
<td>57 (70.4)</td>
</tr>
<tr>
<td>Occupation, level of training</td>
<td></td>
</tr>
<tr>
<td>Nurse</td>
<td>25 (30.9)</td>
</tr>
<tr>
<td>Attending physician</td>
<td>1 (1.2)</td>
</tr>
<tr>
<td>Other, RT, paramedic</td>
<td>2 (2.5)</td>
</tr>
<tr>
<td>Medical student</td>
<td>8 (9.9)</td>
</tr>
<tr>
<td>Resident</td>
<td>45 (55.6)</td>
</tr>
<tr>
<td>Last basic life support course taken, mo</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>4 (4.9)</td>
</tr>
<tr>
<td>&lt;12</td>
<td>46 (56.8)</td>
</tr>
<tr>
<td>&gt;12</td>
<td>31 (38.3)</td>
</tr>
<tr>
<td>Last advanced cardiac life support course taken, mo</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>31 (38.3)</td>
</tr>
<tr>
<td>&lt;12</td>
<td>19 (23.5)</td>
</tr>
<tr>
<td>&gt;12</td>
<td>31 (38.3)</td>
</tr>
<tr>
<td>Last pediatric advanced life support course taken, mo</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>18 (22.2)</td>
</tr>
<tr>
<td>&lt;12</td>
<td>34 (42.0)</td>
</tr>
<tr>
<td>&gt;12</td>
<td>29 (35.8)</td>
</tr>
<tr>
<td>CCs on actual pediatric patient within 2 y</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>42 (51.9)</td>
</tr>
<tr>
<td>1-5 Times</td>
<td>34 (42.0)</td>
</tr>
<tr>
<td>≥6 Times</td>
<td>5 (6.2)</td>
</tr>
<tr>
<td>CCs on manikin within 2 y</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>19 (23.5)</td>
</tr>
<tr>
<td>1-5 Times</td>
<td>48 (59.3)</td>
</tr>
<tr>
<td>≥6 Times</td>
<td>14 (17.3)</td>
</tr>
</tbody>
</table>

Abbreviations: CCs, chest compressions; JIT, just-in-time; RT, respiratory therapist; VisF, visual feedback.
Quality of CPR
The overall quality of CPR was poor. The mean percentages of CCs with adequate depth in each study arm were 12.7% for the control, 37.9% for JIT alone, 33.4% for VisF alone, and 48.0% for JIT plus VisF (Table 2). The mean percentages for a CC rate of 100 to 120 per minute were 27.1% for the control, 40.7% for JIT alone, 68.8% for VisF alone, and 79.2% for JIT plus VisF (Table 3). The CCFs were 90.8% for the control, 89.5% for JIT alone, 91.7% for VisF alone, and 90.5% for JIT plus VisF (eTable 3 in the Supplement).

JIT vs No JIT CPR Training Before CPA
The use of JIT CPR training before CPA resulted in a 19.9% (95% CI, 11.1%-28.7%; P < .001) absolute increase (ie, an 86.3% relative increase) in CC depth compliance compared with no JIT (Table 2) and a 12.0% (95% CI, 0.8%-23.2%; P = .04) absolute increase (ie, a 25.0% relative increase) in compliance with rate guidelines (Table 3). The CCF was uniformly high, and no significant increase in CCF was found with the use of JIT CPR training (eTable 3 in the Supplement).

VisF vs No VisF During CPA
The use of real-time VisF during CPA resulted in a 15.4% (95% CI, 6.6%-24.2%; P = .001) absolute increase (ie, a 60.9% relative increase) in CC depth compliance and a 40.1% (95% CI, 28.8%-51.3%; P < .001) absolute increase (ie, a 118.3% relative increase) in CC rate compliance compared with no VisF. The CCF was uniformly high, and no significant increase in CCF was found with the use of real-time VisF (eTable 3 in the Supplement). Figure 2 shows the main effect of JIT CPR training before CPA and VisF during CPA on the quality of CPR.
Interaction Effect

Combined JIT CPR training and real-time VisF showed the highest compliance with AHA CPR guidelines for CC depth and rate. However, the interaction effect between JIT and VisF was not statistically significant (P = .24 for CC depth, P = .77 for CC rate, and P = .73 for CCF).

Discussion

This prospective, randomized clinical study evaluated the effect of JIT CPR training before CPA and real-time VisF during CPA on the quality of CPR across multiple institutions. Our results showed that certified health care professionals struggle to provide guideline-compliant CCs during CPA in a simulated, team-based environment. We demonstrated that JIT CPR training before CPA or real-time VisF during CPR, alone or in combination, improves compliance with AHA guidelines for CPR quality.

Two previous simulator-based studies with single rescuers demonstrated poor quality of CPR, with deterioration of CC quality following training. Pediatric health care professionals in a tertiary care center struggled to achieve AHA guidelines when performing CPR on real patients. While the performance of CPR in our control group was poor for CC depth and rate, the JIT and VisF–trained group had better CC quality than those who had received bedside JIT CPR training with no video component and those who had real-time VisF during the performance of CPR on real pediatric patients.

JIT CPR Training

The JIT CPR training before CPA, or training defined as “a training session conducted directly prior to... and at/near the site of the potential intervention,” has emerged as a potential solution to address the poor retention of CPR skills after basic life support education. The provision of frequent JIT CPR training with integrated feedback (and no video-based learning) has been shown to improve the time to achieve CPR skills success and retention of CPR skills. In a study of adults, Bobrow et al showed that the use of real-time feedback during resuscitation training improved CPR quality and survival in patients with out-of-hospital CPA. Recently, the AHA announced the launch of the Resuscitation Quality Improvement program, consisting of JIT CPR training with integrated feedback and video-based learning. The widespread uptake of this program may eventually replace traditional basic life support training for health care professionals.

To our knowledge, our study is the first to date to evaluate JIT CPR training with integrated video-based learning and VisF before CPA in a manner mirroring the design of the AHA’s Resuscitation Quality Improvement program. We found significant improvements in CC depth and rate with a brief, focused JIT training session, establishing proof of concept supportive of this design. This evidence supports the implementation of JIT training in clinical environments where CPA is more common (eg, the intensive care unit). The timing, intensity, and frequency of JIT CPR training, as well as the minimally required cutoff for CPR competency, are variables that should be explored in future research to guide the design of JIT CPR training programs.

Visual Feedback

The use of CPR feedback technology has demonstrated benefits for improving the quality of CPR in the context of CPA by 1 or 2 rescuers in the simulated environment. Human studies with adult patients in CPA demonstrate that the use of CPR feedback improves CPR quality and accelerates the rate of return of spontaneous circulation when combined with postevent debriefing. In our study, we found a significant improvement in CC depth and a more substantial improvement in CC rate with the use of VisF during simulated CPA. The lack of a more substantial improvement in CC depth suggests that additional focused training may be necessary, particularly given the association of increased CC depth with improved survival. In contrast, the pronounced improvement in CC rate, as well as recent single-center evidence demonstrating similar improvements in CPR quality in real patients, provides compelling evidence to support the widespread implementation of real-time VisF during CPA. Various factors likely influence the effectiveness of VisF during CPA, including health care professional responsiveness to VisF, the duration of CPA, patient age, and the number of health care professionals performing CPR. Future work should describe how health care professionals interact with VisF devices, demonstrate how teams can optimally integrate VisF, and assess whether VisF during CPR improves patient outcomes from CPA across multiple institutions.

Limitations

Despite the attention to multicenter standardization, our study had several limitations. We had one simulated CPA scenario, with 2 team members providing CPR. As such, the results of our study reflect this specific simulated context, making it difficult to predict if our results are directly generalizable to patient care. We had 45 minutes between JIT CPR training and the CPA scenario, while in a real clinical environment, the delay between JIT CPR training and the provision of CPR is unpredictable. Furthermore, participants in the JIT CPR training groups received only one JIT training session. The eventual quality of CPR provided was likely influenced by these factors (ie, the time delay between JIT training and a CPA event and the frequency of JIT training). We excluded participants who had previous experience with CPR feedback devices from our study to remove this as a confounding variable. As such, the effect of the identical interventions on health care professionals with previous experience using CPR feedback devices was not assessed. We believe that the results of our study are generalizable to similar health care professionals naive to CPR feedback devices across a broad spectrum of geographic locations.

Because of limitations in VisF technology, we did not collect data for several variables such as ventilation rate, tidal volume, and residual leaning force. Last, we executed an intent-to-treat analysis. Variable compliance with VisF may have affected the results but would have imparted selection and ascertainment bias on the analysis.
Conclusions

The quality of CPR provided by health care professionals is poor. It is feasible to improve CPR quality using a simple visual CPR-quality feedback device during JIT CPR training (with video) or during a simulated CPA event (with real-time feedback). The JIT CPR training or real-time VisF during CPR can improve compliance with AHA guidelines for CPR quality that are associated with better survival outcomes.

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Accepted for Publication: September 16, 2014.


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Author Contributions: Drs Cheng and Lin had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Acquisition, analysis, or interpretation of data: Cheng, Brown, Duff, Davidson, Overly, ToftI, Peterson, White, Bank, Gottesman, Adler, Zhong, V. Grant, D. J. Grant, Marohn, Charnovich, Hunt, Kessler, Wong, Robertson, Lin, Duval-Arnould, Nadkarni.

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Statistical analysis: Hunt, Wong, Lin, Doan.

Obtained funding: Cheng, Gottesman, V. Grant, Hunt. Administrative, technical, or material support: Brown, Davidson, Overly, ToftI, Peterson, Bhanji, Bank, Gottesman, Adler, V. Grant, D. J. Grant, Sudikoff, Marohn, Charnovich, Robertson, Duval-Arnould.

Study supervision: Cheng, Brown, Davidson, Research, Laerdal Corporation donated CPRcards and loanded each recruitment site a SimJunior manikin for use in the study. Data collection for one site (Columbia University College of Physicians and Surgeons) was supported by grant U10 HD07618 from the National Institutes of Health. S01HL085669-10 from the National Institute of Neurological Disorders and Stroke, and RO1 HL114484 and 1U10LO94345-01 from the National Heart, Lung, and Blood Institute. No other disclosures were reported.

Funding/Support: This study was funded by a research grant from the Heart and Stroke Foundation of Canada and the Canadian Institute for Health Research. Perishock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. Circulation. 2011;124:158-66.

Role of the Funder/Sponsor: The research grant funds from the Heart and Stroke Foundation of Canada and the Canadian Institute for Health Research were used for the design and conduct of the study, as well as the collection, management, analysis, and interpretation of data. No funds were received from Laerdal Corporation for conducting this research. Other funding sources had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

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Improving CPR With a CPR Feedback Device