The Influence of Scenario-Based Training and Real-Time Audiovisual Feedback on Out-of-Hospital Cardiopulmonary Resuscitation Quality and Survival From Out-of-Hospital Cardiac Arrest

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INTRODUCTION

Background and Importance

Communities in North America report wide disparities in outcomes from out-of-hospital cardiac arrest.\(^1,^2\) Although many report poor outcomes, several have achieved significantly higher survival rates\(^1,^2\) that are likely a result of multiple factors, with one possible component being out-of-hospital cardiopulmonary resuscitation (CPR) quality. There is preclinical and clinical evidence demonstrating that high-quality CPR (defined by the hemodynamically important components chest compression depth,\(^3-^7\) chest compression fraction,\(^8-^1^3\) preshock pause,\(^1^4-^1^6\) chest compression release velocity \("recoil"\),\(^1^7-^1^9\) chest compression rate,\(^1^5,^2^0\) and ventilation\(^2^1\)) improves outcomes. Although the 2010 American Heart Association (AHA) Guidelines place a clear emphasis on minimally interrupted, high-quality CPR, it remains to be determined whether individual communities can improve
Editor's Capsule Summary

What is already known on this topic
Despite decades of cardiac arrest research, functional survival after out-of-hospital cardiac arrest has not improved substantially.

What question this study addressed
Whether a "bundle" of a cardiopulmonary resuscitation training program emphasizing performance metrics and the use of real-time audiovisual feedback improves survival for out-of-hospital cardiac arrest victims.

What this study adds to our knowledge
In this before-after trial of 484 patients, unadjusted survival to discharge with favorable functional outcomes was 6.5% in the before group and 10.8% (difference 4.2%; 95% confidence interval [CI] −0.8% to 9.2%) after implementation of the bundle, and the adjusted odds ratio was 2.69 (95% CI 1.04 to 6.94).

How this is relevant to clinical practice
Within the limitations of a study design that is vulnerable to temporal confounding, this study suggests that this approach might be beneficial.

outcomes by systematically improving the CPR quality delivered by out-of-hospital providers.

In addition to novel approaches to CPR training, real-time audiovisual feedback has been shown to improve CPR quality in actual arrest scenarios both inside and outside the hospital.5,22,23 Hostler et al24 showed improvement in CPR quality metrics but not outcomes when real-time audiovisual feedback was used in the out-of-hospital setting. Edelson et al6 demonstrated that real-time audiovisual feedback used for in-hospital arrests improved CPR quality and increased rates of return of spontaneous circulation. For in-hospital training, Wayne et al25,26 and Wayne and McGaghie27 showed significant improvement in CPR performance with simulations and a team approach.

Goals of This Investigation
Our a priori hypothesis was that an out-of-hospital initiative aimed at improving CPR quality by implementing (1) scenario-based CPR training, emphasizing a team approach to resuscitation and the importance of CPR quality metrics, and (2) real-time audiovisual feedback during CPR would improve CPR quality and survival from out-of-hospital cardiac arrest.

MATERIALS AND METHODS
Setting
Data were collected from a single fire-based emergency medical services (EMS) agency located in Mesa, AZ, which responds to a suburban population of 439,000 residents, with approximately 70,000 911 calls annually.28 The agency includes 19 fire stations staffed by 202 emergency medical technician (EMT)-paramedics and 171 EMT-basics. A typical responding crew includes 2 EMT-paramedics and 2 EMT-basics. Additionally, a privately contracted ambulance company assists the fire-based rescuers with patient transport to hospitals. The Mesa Fire/Medical Department participates in the statewide cardiac resuscitation public health initiative called "SHARE—Save Hearts in Arizona Registry and Education."29 This department has used an innovative minimally interrupted cardiac resuscitation protocol as their standard approach to adult out-of-hospital cardiac arrest from suspected cardiac cause since 2006. Minimally interrupted cardiac resuscitation has been previously described.10

Out-of-hospital cardiac arrest has been designated a major public health problem by the Arizona Department of Health Services. SHARE is the designated public health program created to measure response to out-of-hospital cardiac arrest and improve outcomes. Thus, the SHARE Program initiatives and its data collection are exempt from the Health Insurance Portability and Accountability Act. By virtue of SHARE being a health department-sponsored public health initiative, the Arizona Department of Health Services' Human Subjects Review Board and the University of Arizona institutional review board have determined that neither the interventions nor their evaluation constitutes human subjects research and have approved the publication of deidentified data.

Study Design and Selection of Participants
This is a prospective, before-after, observational cohort study of consecutive adult patients (aged ≥18 years) with out-of-hospital cardiac arrest of presumed cardiac cause who had out-of-hospital initiation of CPR. Cases were excluded from analysis if resuscitation was not initiated, the patient had a do-not-resuscitate order, arrest was witnessed by EMS, or the cause of the arrest was presumed to be noncardiac.

Interventions
Eighteen months' worth of baseline CPR quality and outcome data (October 7, 2008, to March 31, 2010) were collected during phase 1 (before). Real-time audiovisual feedback was not enabled during phase 1. The subsequent intervention included 2 hours of didactic teaching, along with 2 hours of team-centered psychomotor practice using scenario-based training, and activation of real-time audiovisual feedback. Didactic education and scenario-based training repeatedly and explicitly emphasized a team approach to resuscitation and meticulous compliance with the parameters of high-quality CPR within their minimally interrupted cardiac resuscitation protocol. Providers were educated about specific positioning and the role of each team member in a "pit crew" model of resuscitation (Appendix E1, available online at http://www.annemergmed.com), with the intent that this model would be used during actual resuscitations. The prime importance of uninterrupted, high-quality chest compressions was stressed and
the "compressor" was trained to have an unobstructed view of the
defibrillator to enhance the effectiveness of real-time audiovisual
feedback. In addition to the initial training, 10-minute videos were
shown for both 2- and 4-provider crews to reinforce the patterned
approach to resuscitation (see http://azdhs.gov/azshare/ccr_-
share.htm). Providers were specifically trained to avoid excessive
ventilation (both rate and volume) and were educated to use the
CPR interval timer (on the defibrillator) to space ventilations
properly (ie, deliver 1 ventilation every 6 seconds). The training
emphasized the importance of applying the combination
defibrillator pads/accelerometer without interrupting compressions.

The monitor-defibrillator used in this study provides real-
time audiovisual feedback through both audio and visual
prompts. The visual display allows the compressor to see
multiple, real-time, compression-to-compression quality
parameters, including absolute compression depth, absolute
compression rate, and a measure that includes a weighted
summary analysis of depth, rate, and compression fraction
(Appendix E1, available online at http://www.annemergmed.
com). When compressions are discontinued for at least 3
seconds, an idle timer is prominently displayed, reminding the
compressor to resume CPR. Rate and depth measurements are
displayed numerically on the monitor. If compressions are
performed outside of the target depth or rate (ie, depth <2
inches, rate <90 or > 120 compressions/minute), the parameter
label (rate or depth) and its numeric value are illuminated with a
distinct red highlight that serves as a visual "alarm." The text "Fully
Release" is automatically displayed every 30 seconds. An audio
metronome, set to 100 compressions per minute, sounds any time
compressions are performed. All other audio prompts related to
CPR quality (eg, "push harder," "good compressions") remained
disabled in both phases. The "charge during CPR" feature was
enabled during phase 2 (after) to automatically charge the
defibrillator before the end of each 2-minute chest compression
interval, with the goal of minimizing compression interruptions
while waiting for the defibrillator to charge.

On April 6, 2010, a 4-hour training session was conducted
with 9 "master trainers," who later trained the remaining 364
providers between April 7, 2010, and April 29, 2010. Phase 2
began on May 27, 2010, after training was completed and the
real-time audiovisual feedback and new software were enabled
on the monitor-defibrillators.

Methods of Measurement

Chest compression quality was measured during resuscitation
with a monitor-defibrillator (E-series; ZOLL Medical, Chelmsford,
MA) with Food and Drug Administration–approved accelerometer-
based technology that measures chest compression fraction, depth,
rate, and rate of recoil. The accelerometer is integrated into
defibrillator pads that are used for patient monitoring and
defibrillation. The defibrillator units are equipped with Food and
Drug Administration–approved technologies that provide real-time
audiovisual feedback on the quality of compressions.

Chest compression fraction was measured as the
percentage of time compressions were performed (when
indicated) throughout the entire resuscitation event.
Compressions were considered indicated any time a patient
was without spontaneous pulses (as documented in the
patient care report and confirmed by ECG) during out-of-
hospital care (ie, excluded data after arrival at the emergency
department [ED]) and when compression data were valid (ie,
the pads were connected and adhered properly). Time was
not allotted for the performance of interventions such as
ventilation, defibrillation, or intubation (ie, the timer
continued to run during all interventions). FRESH shock
calculated as the number of seconds without ongoing
compressions before shock delivery for patients with a
shockable rhythm (ventricular fibrillation/tachycardia).
"Ongoing" compressions were defined as at least 5 back-to-
back compressions. Recoil was measured as the peak chest
compression release velocity (milli-inches/second) during
each compression. Ventilation rates were averaged for each
minute of postintubation EMS care without return of
spontaneous circulation. Ventilations were captured with the
end-tidal CO₂ waveform from a sidestream ETCO₂ adaptor
(LoFlo Sidestream CO₂ Module; Philips/Respironics;
Wallingford, CT), which was placed after intubation. ETCO₂
values were averaged for each case from all out-of-hospital
minutes containing valid ETCO₂ data without return of
spontaneous circulation. Minutes with ETCO₂ values greater
than 40 mm Hg were no; averaged because they may have
been associated with return of spontaneous circulation.

The SHARE program has been previously described in detail
and includes a voluntary Utstein-style out-of-hospital cardiac
arrest EMS database linked with inhospital postarrest process
and outcome data from hospitals.29 Data collected from
participating EMS systems and hospitals are entered into an
ACCESS 2007 (Microsoft Corporation, Redmond WA)
database maintained on a secure server at the University of
Arizona. The SHARE database is mapped to the Cardiac Arrest
Registry to Enhance Survival Registry, the largest national out-
of-hospital cardiac arrest reporting system
(http://www.mycares.net). The SHARE database has multiple
logic constraints for out-of-hospital cardiac arrest data elements.
For example, arrival in the ED cannot occur before collapse. When
values outside the realm of physical possibility are encountered or
are missing for any of the Utstein data elements, secondary and
tertiary data sources (such as private ambulance transporting first
care reports or hospital ED records) are referenced, which allows
the backfilling of missing data elements or confirmation of
suspected erroneous elements. Additionally, each record goes
through a manual review before being committed to the data set.
Minimally interrupted cardiac resuscitation protocol compliance
was determined by all 4 components: 200 preshock chest
compressions, 200 postshock chest compressions, delayed
intubation attempt for 3 cycles of 200 compressions and rhythm
analysis, and patients having received intravenous epinephrine in
the first or second cycle of chest compressions.

Volume 62, No. 1 : July 2013
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Outcome Measures

The main outcome variables were survival to hospital discharge, favorable functional outcome (Cerebral Performance Category score of 1 or 2) as measured at hospital discharge by formally trained hospital personnel, and CPR quality. These outcomes were compared between study phases (phase 1 versus phase 2), the main independent variable. Additional confounders and risk factors considered were initial cardiac rhythm on EMS arrival (initial rhythm), EMS dispatch-to-on-scene arrival interval (response interval), age, sex, location of arrest, witnessed versus unwitnessed arrest, provision of bystander CPR, the use of therapeutic hypothermia, and minimally interrupted cardiac resuscitation protocol compliance.

CPR quality measures included the following: chest compression fraction, depth, rate, and release velocity; preshock and postshock pause; and ventilation rate.

Primary Data Analysis

For univariate analyses, Fisher’s exact test (proportions), t test (means), or Kruskal-Wallis test (medians) was used, with \( \alpha = .05 \). Summary statistics are reported as percentages, means with 95% confidence intervals (CIs), and medians with interquartile ranges. Absolute differences with 95% CIs are reported for comparisons of means, medians, and proportions. To calculate crude and adjusted odds ratios (ORs) for survival and favorable functional outcome, we used multivariable mixed-effects logistic regression (xtmelogit, Stata version 12.1; StataCorp, College Station, TX), with the hospital providing final care as the random effect and all patients not transported as a single cluster. Covariates were included in the final model if the associated \( P \) value from the likelihood ratio \( \chi^2 \) test was less than or equal to .05 or if they were judged to be a significant confounder (inclusion of covariate changed the coefficient for main risk factor >10%) of the relationship between the outcome variable and our main independent variable, pre-versus postperiod. We calculated the Hosmer-Lemeshow goodness-of-fit statistic and the area under the receiver operating characteristics curve for each final multivariable model, using the predicted probabilities incorporating the random effects from the mixed-effects modeling. We also explored model diagnostics for the mixed-effects model by examining final model residuals (Pearson, deviance, and Anscombe) to identify overly influential covariate patterns or outliers that could represent miscoded cases. We also examined model diagnostics (leverage, deviance, etc) for all final models, assuming no random effects (ordinary logistic regression), as an additional approach to identifying potential outliers. Fractional polynomial regression was used to examine the linear relationship of continuous variables with the outcome variables in the logit scale.

Univariate multiple imputation methods and approaches were explored to handle missing values for the chest compression quality metrics (mean depth, mean rate, recoil, compression fraction, percentage of compression =2 inches, mean preshock and postshock pause), using the following variables as covariates for imputation: survival to discharge, pre/postperiod, out-of-hospital return of spontaneous circulation, age, sex, witnessed arrest, shockable rhythm (ventricular fibrillation/ventricular tachycardia), bystander CPR, location of arrest, and EMS response interval. The pattern of missing data was first explored with univariate analyses to examine associations between a patient’s having missing data and study covariates. Because all CPR quality data were missing for a case with any missing CPR quality data, each CPR quality metric was imputed independently. Twenty imputed data sets were created for analysis with linear regression ("mi impute regress" with random number seed “4987”), and all chest compression quality metrics were compared between phase 1 and phase 2 with either linear or median regression, as appropriate, with associated 95% CIs for differences. Ventilation and \( \text{ETCO}_2 \) data were not amenable to imputation because we could not identify the time of intubation for all patients and thus were not able to determine which patients were intubated before sustaining return of spontaneous circulation. Thus, ventilation data are compared between the phase 1 and phase 2 with nonimputed data.

We conducted a post hoc analysis to identify potential secular trends or a Hawthorne effect in all-rhythm survival and positive functional outcomes by dividing phase 1 into halves and comparing outcomes (survival and functional outcome) between them. In addition, we investigated the proportion of patients who were not transported to a hospital but were treated by EMS on scene in phase 1 versus phase 2 to assess whether this was associated with any outcome differences between periods. All statistical analyses and imputations were performed with Stata (version 12.1).
RESULTS

Characteristics of Study Subjects

A total of 232 consecutive, adult, non-EMS-witnessed, out-of-hospital cardiac arrests of presumed cardiac cause with resuscitation initiated in the field occurred in phase 1 and 252 in phase 2 (see Figure for inclusion/exclusion flow chart). Among the 484 patients in this analysis, 1 was missing survival data and 3 were missing functional outcome scores. A total of 147 patients (30.4%) were missing CPR quality data, and 71 of 228 patients (31.1%) who received shock were missing pre/post shock pause data. A comparison of demographics and standard Utstein data elements is presented in Table 1. Patient characteristics of phase 1 and phase 2 were similar. Overall, 113 of 484 patients (23.4%) achieved return of spontaneous circulation in the out-of-hospital setting and 55 patients (11.4%) survived to hospital discharge. Of patients with a witnessed arrest and a shockable rhythm, 35 of 93 (37.6%) survived to hospital discharge.

Main Results

Table 2 shows survival and favorable functional outcomes across study periods, along with crude and adjusted ORs. Survival increased from 8.7% (20/231) in phase 1 to 13.9% (35/252) in phase 2 (absolute difference 5.2; 95% CI −0.4 to 10.8), with a crude OR of 1.73 (95% CI 0.93 to 3.21) and an adjusted OR of 2.72 (95% CI 1.15 to 6.41), controlling for witnessed arrest, initial rhythm, provision of therapeutic hypothermia, age, and minimally interrupted cardiac resuscitation protocol compliance. Favorable functional outcome increased from 6.5% in phase 1 to 10.8% in phase 2 (absolute difference 4.2%; 95% CI −0.8% to 9.2%), with a crude OR of 1.76 (95% CI 0.88 to 3.52) and an adjusted OR of 2.69 (95% CI 1.04 to 6.94), adjusting for witnessed arrest, provision of therapeutic hypothermia, age, and minimally interrupted cardiac resuscitation protocol compliance. Age as a continuous variable was linear in the logit scale, as determined by fractional polynomial regression. The intraclass correlation (clustereffect) between both survival and favorable functional outcome and hospital was 0.125 (95% CI 0.018 to 0.528) and 0.140 (95% CI 0.023 to 0.532), respectively, and the likelihood ratio test P value comparing mixed effects versus ordinary logistic regression was .02 and .01, respectively, indicating a significant clustereffect and justifying mixed-effects logistic regression. For the final multivariable model for survival to discharge, the Hosmer-Lemeshow goodness of fit P value was .85 and area under the receiver operating characteristics curve for survival was 0.913. For the final model for positive functional outcome, the Hosmer-Lemeshow goodness of fit P value was .30 and the area under the receiver operating characteristics curve was 0.920. In witnessed arrests with a shockable rhythm, survival and functional outcomes improved significantly from phase 1 to phase 2 (survival 26.3% [15/57] to
Table 2. Final logistic regression models for survival and neurologic outcomes (all rhythms and witnessed/shockable).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No./Total (%)</th>
<th>Absolute Difference (95% CI)</th>
<th>Crude OR (95% CI)</th>
<th>Adjusted OR (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survival to Hospital Discharge and Associated OR (95% CI)</strong></td>
<td></td>
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<tr>
<td>Study period</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>20/231 (8.7)</td>
<td>5.2 (−0.4 to 10.8)</td>
<td>1 [Reference]</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Post</td>
<td>35/252 (13.9)</td>
<td>1.73 (0.93 to 3.21)</td>
<td>2.72 (1.15 to 6.41)</td>
<td></td>
</tr>
<tr>
<td>Witnessed arrest</td>
<td></td>
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<tr>
<td>No</td>
<td>13/291 (4.5)</td>
<td>17.4 (11.1 to 23.7)</td>
<td>1 [Reference]</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>42/192 (21.9)</td>
<td>4.19 (2.12 to 8.30)</td>
<td>4.00 (1.72 to 9.28)</td>
<td></td>
</tr>
<tr>
<td>Initial rhythm</td>
<td></td>
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<tr>
<td>Nonshockable</td>
<td>12/334 (3.6)</td>
<td>25.3 (17.7 to 32.8)</td>
<td>[Reference]</td>
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<tr>
<td>VF/VT</td>
<td>43/149 (28.9)</td>
<td>7.33 (3.59 to 14.99)</td>
<td>5.88 (2.59 to 13.36)</td>
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<tr>
<td><strong>Use of TH</strong></td>
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<tr>
<td>No</td>
<td>25/431 (5.8)</td>
<td>51.9 (38.3 to 65.5)</td>
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<td>1 [Reference]</td>
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<tr>
<td>Yes</td>
<td>30/52 (57.7)</td>
<td>0.97 (0.95 to 0.99)</td>
<td>0.98 (0.95 to 1.00)</td>
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<tr>
<td><strong>MICR protocol compliance</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Partial</td>
<td>10/108 (9.3)</td>
<td>2.7 (−3.6 to 9.1)</td>
<td>1 [Reference]</td>
<td>1 [Reference]</td>
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<tr>
<td>Complete</td>
<td>45/375 (12.0)</td>
<td>2.02 (0.96 to 4.28)</td>
<td>1.16 (0.46 to 2.93)</td>
<td></td>
</tr>
<tr>
<td><strong>Favorable Functional Outcome (CPC score=1 or 2), OR (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No./Total (%)</td>
<td>15/230 (6.5)</td>
<td>4.2 (−0.8 to 9.2)</td>
<td>1 [Reference]</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Absolute Difference (95% CI)</td>
<td>27/251 (10.8)</td>
<td>1.76 (0.88 to 3.52)</td>
<td>2.69 (1.04 to 6.94)</td>
<td></td>
</tr>
</tbody>
</table>

VF, Ventricular fibrillation; VT, ventricular tachycardia.

*Adjusted for all variables listed in this table in final model (likelihood ratio P value for all variables included in final model < .05 or judged a significant confounder).

Our post hoc analysis for potential secular trends or age-age interaction showed that the older patients had significantly higher death rates than younger patients. The absolute difference was 3.9% (95% CI, 0.8% to 7.0%). The absolute difference in prehospital CPR rates was 8.6% (95% CI, 3.2% to 13.9%). The absolute difference in the use of TH was 21.8% (95% CI, 15.3% to 28.3%). The absolute difference in the use of MICR was 42.2% (95% CI, 33.1% to 51.3%). The absolute difference in the use of advanced cardiac life support was 29.6% (95% CI, 20.8% to 38.4%). The absolute difference in the use of ECMO was 14.2% (95% CI, 7.8% to 20.6%). The absolute difference in the use of mechanical ventilation was 16.7% (95% CI, 10.2% to 23.2%). The absolute difference in the use of hypothermia was 20.4% (95% CI, 14.5% to 26.3%). The absolute difference in the use of thiamine was 11.1% (95% CI, 5.6% to 16.6%). The absolute difference in the use of atropine was 26.1% (95% CI, 19.5% to 32.7%). The absolute difference in the use of lidocaine was 17.8% (95% CI, 11.5% to 24.1%). The absolute difference in the use of epinephrine was 21.2% (95% CI, 15.5% to 26.9%). The absolute difference in the use of amiodarone was 29.3% (95% CI, 22.8% to 35.8%). The absolute difference in the use of propofol was 25.8% (95% CI, 19.6% to 32.1%). The absolute difference in the use of lorazepam was 14.4% (95% CI, 8.7% to 20.1%). The absolute difference in the use of midazolam was 20.6% (95% CI, 14.9% to 26.3%). The absolute difference in the use of fentanyl was 23.1% (95% CI, 17.4% to 28.8%). The absolute difference in the use of naloxone was 16.8% (95% CI, 11.1% to 22.5%). The absolute difference in the use of atropine was 21.2% (95% CI, 15.5% to 26.9%). The absolute difference in the use of amiodarone was 29.3% (95% CI, 22.8% to 35.8%). The absolute difference in the use of propofol was 25.8% (95% CI, 19.6% to 32.1%). The absolute difference in the use of lorazepam was 14.4% (95% CI, 8.7% to 20.1%). The absolute difference in the use of midazolam was 20.6% (95% CI, 14.9% to 26.3%). The absolute difference in the use of fentanyl was 23.1% (95% CI, 17.4% to 28.8%). The absolute difference in the use of naloxone was 16.8% (95% CI, 11.1% to 22.5%).
The thrust of the current literature supports the concept that CPR quality is an important factor in survival from out-of-hospital cardiac arrest.1,21,24-35 This issue is strongly emphasized in the 2010 AHA guidelines.32 This analysis demonstrates that a systematic and comprehensive approach to improving out-of-hospital CPR quality in a large EMS system was associated with achieving the 2010 AHA guideline recommendations for CPR quality, an increase in survival to hospital discharge, and favorable functional outcomes.

These results demonstrate an improvement in CPR quality performance in line with the 2010 AHA guidelines for all phases.
metrics and, most important, increased adjusted odds of survival and favorable functional outcome in our postintervention group (Tables 2 and 3). According to current understanding of the effects of CPR during cardiac arrest and the quality of CPR in most actual resuscitations, our findings are both biologically plausible and logical. For example, one major contributor to the low survival rates in most settings is prolonged inadequate myocardial and cerebral blood flow. During resuscitation efforts, the forward blood flow generated by CPR is marginal, and as such, any pause in compressions or compressions of inadequate depth have a significant negative effect on both defibrillation success and survival. Cardiac output is the major determinant of carbon dioxide delivery to the lungs during CPR. In our analysis, the higher ET CO2 in phase 2 provides strong evidence for improved CPR quality during phase 2 and was likely the result of increased perfusion.

The recognition of the importance of continuous blood flow and the consequences of interrupting myocardial and cerebral perfusion has led to great interest in CPR quality. Numerous animal and clinical studies have demonstrated that CPR quality (chest compression depth,17 fraction,8-13 preshock pause,14-16 recoil,17-19 chest compression rate,13,20 and ventilation rate21) has a significant effect on cardiac arrest outcomes. In 2007, Kramer-Johansen et al24 recently performed a large (1,586 subjects) cluster-randomized study within the Resuscitation Outcome Consortium to assess the effect of real-time audiovisual feedback on CPR quality and outcomes. Although they found improvements in CPR quality with feedback on compared with feedback off (compression fraction 66% versus 64%, respectively, P=.02; depth 40 mm versus 38 mm, P=.005; rate

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases With Missing CPR Depth, Rate, Recoil, and Compression Fraction</th>
<th>Cases Not Missing CPR Quality Metrics Data</th>
<th>Absolute Difference, Not Missing/Missing (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total, No. (%)</td>
<td>N=147 %30.4</td>
<td>N=337 %69.6</td>
<td>NA</td>
</tr>
<tr>
<td>Study period, No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre (phase 1)</td>
<td>N=86 %58.5</td>
<td>N=146 %43.3</td>
<td>15.2 (%5.6 to 24.7)</td>
</tr>
<tr>
<td>Post (phase 2)</td>
<td>N=61 %41.5</td>
<td>N=191 %56.7</td>
<td></td>
</tr>
<tr>
<td>Age, median (IQR), y</td>
<td>N=56-80</td>
<td>N=56-78</td>
<td>4 (%8.0 to 15.9)</td>
</tr>
<tr>
<td>Male sex, No. (%)</td>
<td>N=61 %61.9</td>
<td>N=91 %68.6</td>
<td>6.6 (%2.6 to 15.9)</td>
</tr>
<tr>
<td>Witnessed arrest, No. (%)</td>
<td>N=33.3</td>
<td>N=144 %42.7</td>
<td>9.4 (0.1 to 18.7)</td>
</tr>
<tr>
<td>Shockable rhythm on EMS arrival, No. (%)</td>
<td>N=26.5</td>
<td>N=111 %32.9</td>
<td>6.4 (%2.3 to 15.1)</td>
</tr>
<tr>
<td>Provision of bystander CPR, No. (%)</td>
<td>N=53 %36.1</td>
<td>N=139 %41.3</td>
<td>5.2 (%4.2 to 14.6)</td>
</tr>
<tr>
<td>Location of arrest, No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>N=105 %71.4</td>
<td>N=248 %73.6</td>
<td>2.2 (%6.5 to 10.9)</td>
</tr>
<tr>
<td>Medical facility</td>
<td>N=25 %17.0</td>
<td>N=43 %12.8</td>
<td>4.2 (%11.3 to 2.8)</td>
</tr>
<tr>
<td>Public</td>
<td>N=17 %11.6</td>
<td>N=46 %13.7</td>
<td>2.1 (%4.3 to 8.4)</td>
</tr>
<tr>
<td>EMS response interval, median (IQR), min</td>
<td>N=5 (4-6)</td>
<td>N=5 (5-6)</td>
<td>0</td>
</tr>
<tr>
<td>Use of therapeutic hypothermia, No. (%)</td>
<td>N=61 %61.9</td>
<td>N=43 %12.8</td>
<td>6.6 (1.4 to 11.9)</td>
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<tr>
<td>MICR protocol compliance, No. (%)</td>
<td>N=74.8</td>
<td>N=265 %78.6</td>
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<td>Return of spontaneous circulation, No. (%)</td>
<td>N=12.9</td>
<td>N=94 %27.9</td>
<td>15.0 (%7.7 to 22.2)</td>
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<tr>
<td>Survival to hospital discharge for all rhythms, No./total (%)</td>
<td>13/146, 8.9</td>
<td>42/337, 12.5</td>
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<td>Favorable functional outcome (CPC score=1 or 2) for all rhythms, No./total (%)</td>
<td>10/145, 6.9</td>
<td>32/336, 9.5</td>
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</tr>
</tbody>
</table>

NA, Not applicable.

*One outcome missing.

†Three outcomes missing.

metrics and, most important, increased adjusted odds of survival and favorable functional outcome in our postintervention group (Tables 2 and 3). According to current understanding of the effects of CPR during cardiac arrest and the quality of CPR in most actual resuscitations, our findings are both biologically plausible and logical. For example, one major contributor to the low survival rates in most settings is prolonged inadequate myocardial and cerebral blood flow. During resuscitation efforts, the forward blood flow generated by CPR is marginal, and as such, any pause in compressions or compressions of inadequate depth have a significant negative effect on both defibrillation success and survival. Cardiac output is the major determinant of carbon dioxide delivery to the lungs during CPR. In our analysis, the higher ET CO2 in phase 2 provides strong evidence for improved CPR quality during phase 2 and was likely the result of increased perfusion.

The recognition of the importance of continuous blood flow and the consequences of interrupting myocardial and cerebral perfusion has led to great interest in CPR quality. Numerous animal and clinical studies have demonstrated that CPR quality (chest compression depth, fraction, preshock pause, recoil, chest compression rate, and ventilation rate) has a significant effect on cardiac arrest outcomes. In 2007, Kramer-Johansen et al recently performed a large (1,586 subjects) cluster-randomized study within the Resuscitation Outcome Consortium to assess the effect of real-time audiovisual feedback on CPR quality and outcomes. Although they found improvements in CPR quality with feedback on compared with feedback off (compression fraction 66% versus 64%, respectively, P=.02; depth 40 mm versus 38 mm, P=.005; rate

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases With Missing CPR Depth, Rate, Recoil, and Compression Fraction</th>
<th>Cases Not Missing CPR Quality Metrics Data</th>
<th>Absolute Difference, Not Missing/Missing (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total, No. (%)</td>
<td>N=147 %30.4</td>
<td>N=337 %69.6</td>
<td>NA</td>
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<tr>
<td>Study period, No. (%)</td>
<td></td>
<td></td>
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<tr>
<td>Pre (phase 1)</td>
<td>N=86 %58.5</td>
<td>N=146 %43.3</td>
<td>15.2 (%5.6 to 24.7)</td>
</tr>
<tr>
<td>Post (phase 2)</td>
<td>N=61 %41.5</td>
<td>N=191 %56.7</td>
<td></td>
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<tr>
<td>Age, median (IQR), y</td>
<td>N=56-80</td>
<td>N=56-78</td>
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<tr>
<td>Male sex, No. (%)</td>
<td>N=61 %61.9</td>
<td>N=91 %68.6</td>
<td>6.6 (%2.6 to 15.9)</td>
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<tr>
<td>Witnessed arrest, No. (%)</td>
<td>N=33.3</td>
<td>N=144 %42.7</td>
<td>9.4 (0.1 to 18.7)</td>
</tr>
<tr>
<td>Shockable rhythm on EMS arrival, No. (%)</td>
<td>N=26.5</td>
<td>N=111 %32.9</td>
<td>6.4 (%2.3 to 15.1)</td>
</tr>
<tr>
<td>Provision of bystander CPR, No. (%)</td>
<td>N=53 %36.1</td>
<td>N=139 %41.3</td>
<td>5.2 (%4.2 to 14.6)</td>
</tr>
<tr>
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Preceding investigators have shown that real-time audiovisual feedback can improve CPR quality. Our findings are consistent with these previous investigations and strongly support the current emphasis that the 2010 AHA guidelines place on high-quality CPR as a means to improve survival. Although causality cannot be proven according to a nonrandomized trial, to our knowledge, this is the first study to demonstrate an association between a dedicated CPR quality initiative using real-time audiovisual feedback and out-of-hospital cardiac arrest outcomes. Furthermore, it is the first report to show an association between performance of the 2010 AHA CPR quality metrics and increased survival. The interventions, which included didactic education, scenario-based training, and real-time audiovisual feedback, were specifically aimed at particular CPR quality metrics. The training emphasized the importance of CPR quality, a team approach to resuscitation, and real-time audiovisual feedback.

Hostler et al recently performed a large (1,586 subjects) cluster-randomized study within the Resuscitation Outcome Consortium to assess the effect of real-time audiovisual feedback on CPR quality and outcomes. Although they found improvements in CPR quality with feedback on compared with feedback off (compression fraction 66% versus 64%, respectively, P=.02; depth 40 mm versus 38 mm, P=.005; rate
103 versus 108, P<.001; percentage with incomplete release 10% versus 15%, P<.001), they did not find improvements in rates of return of spontaneous circulation (44% versus 45%) or survival to hospital discharge (11% versus 12%). And although the study by Hostler et al24 showed statistical improvements in CPR quality, the effect sizes were small and of questionable clinical significance and CPR quality data were missing in 26% of patients. There are several fundamental differences between the study by Hostler et al24 and ours. First, the current investigation included (1) dedicated didactic and scenario-based training emphasizing CPR quality metrics, in addition to real-time audiovisual feedback as part of a bundled approach to improving CPR quality; (2) a major focus on the optimal use of the feedback-capable defibrillator; (3) a specified “pit crew” team approach to resuscitation; and (4) multiple imputation to reduce the likelihood of bias caused by excluding cases with missing CPR process data. Additionally, we used a different feedback device and our training included a targeted and standardized approach to resuscitation, with a focus on maximizing CPR quality.

In this study of out-of-hospital cardiac arrest, a carefully targeted CPR training curriculum in conjunction with real-time audiovisual feedback was independently associated with achievement of the AHA 2010 guideline-recommended metrics for CPR quality and an increased likelihood of both survival to hospital discharge and favorable functional outcome.

The authors would like to acknowledge the Mesa Fire/Medical Department for their commitment to this project. We thank the Ramsey Social Justice Foundation for its contribution and Paula R. Brasil, MA, for her assistance with the manuscript preparation.

Supervising editor: Judd E. Hollander, MD

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Author contributions: BBJ, TFV, AES, JMT, GAS, and DWS conceived and designed the study. BBJ, AES, JMT, SAC, TKM, JS, and GAS supervised the conduct of the study and data collection. BBJ, US, and AES managed the data, including quality control. BBJ, TFV, US, AES, and DWS provided statistical advice on study design and analyzed the data. TFV drafted the article, and all authors contributed substantially to its revision. TFV takes responsibility for the paper as a whole.

Funding and support: By Annals policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). ZOLL Medical contributed to the data collection and training for this study. Drs. Bobrow and Spaite disclose that the University of Arizona receives support from the Medtronic Foundation involving community-based translation of resuscitation science. Dr. Silver is an employee of Zoll Medical Corporation.


Presented at the American Heart Association Resuscitation Science Symposium, November 2011, Orlando, FL.

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REFERENCES

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Appendix E1.
