Implementation of Pit Crew Approach and Cardiopulmonary Resuscitation Metrics for Out-of-Hospital Cardiac Arrest Improves Patient Survival and Neurological Outcome

Christy L. Hopkins, MD; Chris Burk, NREMT-P; Shane Moser, AAS; Jack Meersman, NREMT-P; Clair Baldwin, NREMT-P; Scott T. Youngquist, MD, MSc

Introduction—Survival from out-of-hospital cardiac arrest (OHCA) varies by community and emergency medical services (EMS) system. We hypothesized that the adoption of multiple best practices to focus EMS crews on high-quality, minimally interrupted cardiopulmonary resuscitation (CPR) would improve survival of OHCA patients in Salt Lake City.

Methods and Results—In September 2011, Salt Lake City Fire Department EMS providers underwent a systemwide restructuring of care for OHCA patients that focused on the adoption of high-quality CPR with minimal interruptions and offline medical review of defibrillator data and feedback on CPR metrics. Victims were directed to ST-elevation myocardial infarction receiving centers. Prospectively collected data on patient survival and neurological outcome for all OHCAs were compared. In the postintervention period, there were 407 cardiac arrests with 65 neurologically intact survivors (16%), compared with 330 cardiac arrests with 25 neurologically intact survivors (8%) in the preintervention period. Among patients who survived to hospital admission, a higher proportion in the postintervention period survived to hospital discharge (71/141 [50%] versus 36/98 [37%], *P*=0.037) and had a favorable neurological outcome (65 [46%] versus 25 [26%], *P*=0.0005) compared with patients treated before the protocol changes. The univariate odds ratio or the association between neurologically intact survival (cerebral performance category 1 and 2) and protocol implementation was 2.3 (95% CI 1.4 to 3.7, *P*=0.001). Among discharged patients, the distribution of cerebral performance category scores was more favorable in the postintervention period (*P*<0.0001).

Conclusions—A multifaceted protocol, including several American Heart Assocation best practices for the resuscitation of patients with OHCA, was associated with improved survival and neurological outcome. (*J Am Heart Assoc*. 2016;5:e002892 doi: 10.1161/JAHA.115.002892)

Key Words: cardiac arrest • emergency medical services

In North America, ≈400 000 people experience an out-of-hospital cardiac arrest (OHCA), with survival rates of between 9% and 15%.[1–4] Despite deployment of public access defibrillators in the community, public instruction in bystander cardiopulmonary resuscitation (CPR), the modernization of

emergency medical services (EMS) systems, and multiple revisions to American Heart Association (AHA) guidelines for the treatment of OHCA, a survey of published literature in 2010 reported that survival had remained largely unchanged for >30 years.[5]

Studies have shown significant variability in the survival of OHCA victims between communities and EMS systems, suggesting that either system- or patient-level characteristics affect overall survival.[6] One of the major determinants of variability in patient outcomes within systems has been shown to be the quality of CPR performed during resuscitation[1,7] with poor performance associated with worse outcomes.[8,9]

The 2010 recommendations from the AHA for the care of patients with an OHCA concentrated on the importance of high-quality CPR with minimal interruptions.[10] The AHA defined 5 components of high-performance CPR that were identified as having the greatest impact on maximizing blood flow and improving patient outcomes.[11] The components are maximizing the chest compression fraction (CCF, or the proportion of time that chest compressions are performed during resuscitation),[12,13]

performing chest compressions at a rate of 100 to 120 compressions/min[9] at a compression depth of ≥50 mm,[11,14–18] allowing the chest to recoil completely during the release phase of CPR,[19] and avoiding excessive ventilation.[11]

Even with training, rescuers often perform poorly on each of these components, specifically CCF, compression depth, and ventilation rates.[20–23] Newer defibrillator technology allows for the measurement and recording of CPR metrics with real-time feedback to CPR providers. This allows rescuers to adjust CPR quality during the resuscitation to meet guideline recommendations.[18,24,25] Postincident reviews of compression metrics, ventilation rates, and rhythm management also allow for greater physician oversight and feedback regarding resuscitation quality.

Several studies have shown improved patient outcomes with the implementation of best practice AHA guideline components within EMS systems, including optimized CPR[26–33] and timely review of the quality and performance of CPR by professional rescuers after cardiac arrest.[14,34,35]

We hypothesized that a protocol change that included the implementation of several such best practices within an urban EMS system would result in improved survival in our community.

Methods

Study Setting

The Salt Lake City Fire Department (SLCFD) provides EMS to an urban daytime population of ≈315 000 over a service area of 111 square miles with an annual emergency call volume of ≈30 000. EMS providers attempt resuscitation of, on average, ≈120 OHCA victims annually (range 95 to 130 victims). The department consists of ≈200 Basic Life Support (BLS) and 140 Advanced Life Support (ALS) providers who staff 8 BLS units and 11 ALS units, responding from 14 stations. A tiered dispatch response matrix, determined by Medical Priority Dispatch System® protocols (Priority Dispatch Corp), is used by the local 911 emergency dispatch center, which instructs callers in bystander CPR. For patients determined to have an uncertain breathing status or who are not breathing at all, the nearest available ALS or BLS unit is dispatched. Additional providers are typically deployed to bring ALS level care to the call and assist with chest compressions. An overall resuscitation crew usually consists of 6 to 8 providers.

Study Design

This is an analysis of prospectively collected data regarding the effects of systemwide interventions to improve cardiac arrest survival. The Institutional Review Board at the University of Utah approved the reporting of these results. Informed consent of subjects was waived.

Inclusion Criteria

Consecutive patients with an OHCA and initiation of CPR between September 1, 2008, and December 31, 2014, were included in the study. The beginning of this period corresponds to SLCFD's adoption of an electronic medical record system (ESO Suite, ESO Solutions), which allowed for the performance of structured electronic queries. Cases were identified via periodic search for all incidents in which the provider's primary or secondary impression was of cardiac or respiratory arrest, along with additional queries for the administration of CPR, defibrillation, or administration of epinephrine. Every 6 months, the local database is cross-checked with Utah State Bureau of EMS reports of cardiac arrests identified within the service district.

Exclusion Criteria

Resuscitation attempts were withheld if the victim had irreversible signs of death or a valid do-not-resuscitate (DNR) order. Arrests due to trauma, drowning, or strangulation were excluded from the database.

Intervention

In September 2011, SLCFD implemented a strategy to reduce hands-off time, improve CPR quality, and extend on-scene resuscitation attempts. EMS crews also began directing OHCA patients to ST-elevated myocardial infarction receiving centers that had adopted targeted temperature management protocols and preferentially performed percutaneous coronary interventions, if indicated.[10]

Specifically, the SLCFD strategy included the following additional changes:

1. CPR Quality Improvement Initiatives

   a. Adoption of defibrillator technology that provides real-time CPR feedback (Zoll E Series Defibrillators; Zoll Corp) using specialized defibrillator pads with an attached sternal accelerometer (CPR-D Padz; Zoll Corp). Before implementation, CPR quality was judged visually.

   b. The EMS medical director performed a postincident review of all cardiac arrests. Directed feedback was sent to providers involved in the resuscitation via email (in most cases) and in person (if corrective action was needed). Defibrillator data, which includes all CPR data, were required to be attached to the electronic patient care report (ePCR). The medical director reviewed all code data with the use of specialized software (RescueNet Code Review; Zoll Corp) along with the ePCR and generated a report that provided summary measures of CPR quality (average rate, depth, CCF, preshock and

postshock pauses, and proportion of all compressions within guidelines for both rate and depth), ventilation frequency, analysis of the rhythm interpretation and treatment decisions, and suggestions for improvement. Before implementation, no formal quality assurance process existed for OHCA patients.

c.   Adoption of rhythm-filtering technology (See-Thru CPR®; Zoll Corp) allowed for interpretation of the underlying rhythm, when feasible, with ongoing CPR. When a shockable rhythm was identified, paramedics were instructed to precharge the defibrillator with ongoing compressions and, once charged, the emergency medical technician performing compressions was instructed to initiate an audible countdown to defibrillation, lifting hands off the chest just before defibrillation, and resuming CPR immediately after-
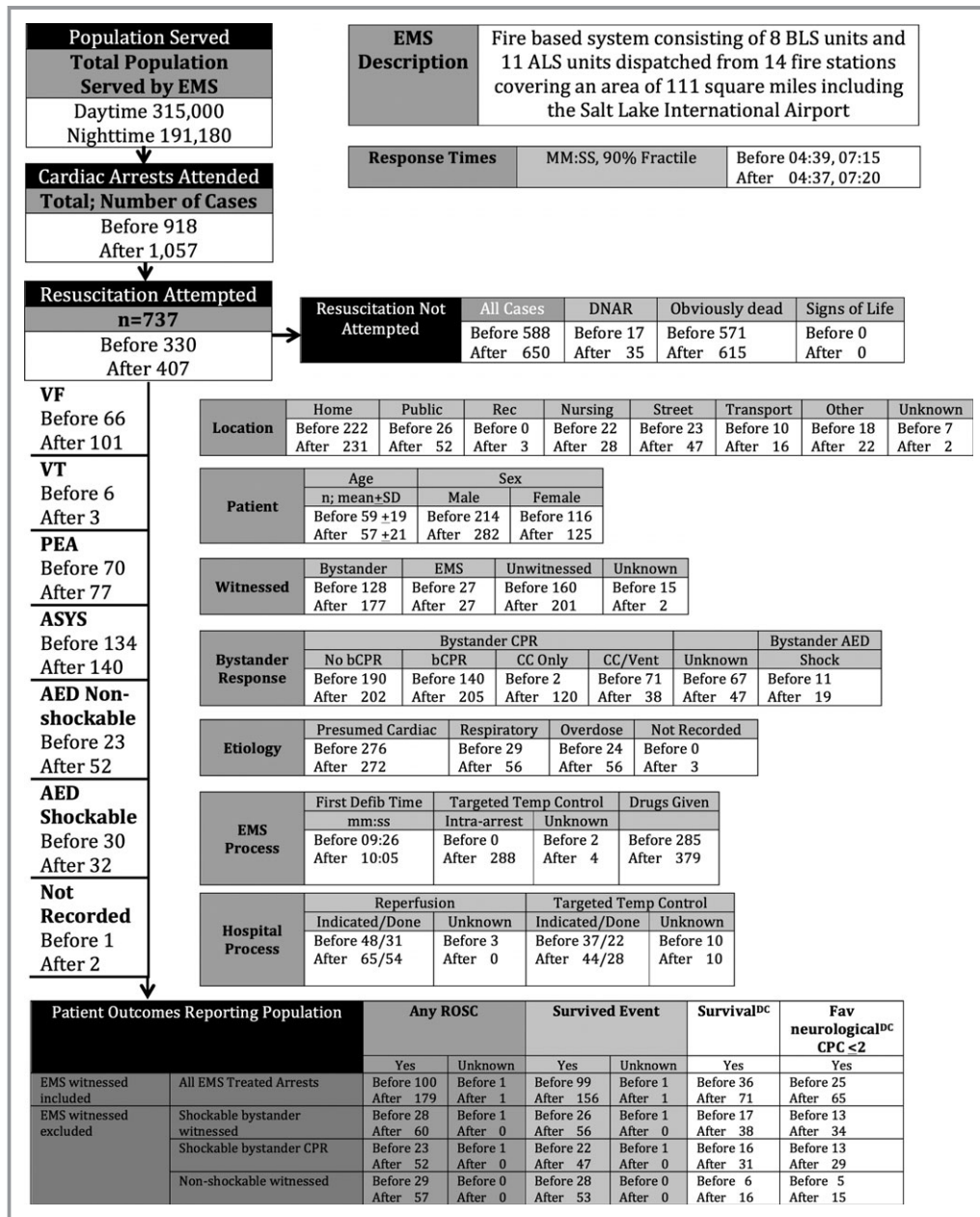
Population Served

Total Population Served by EMS
Daytime 315,000
Nighttime 191,180

Cardiac Arrests Attended — Total; Number of Cases

Before 918
After 1,057

Resuscitation Attempted n=737

Before 330
After 407

EMS Description: Fire based system consisting of 8 BLS units and 11 ALS units dispatched from 14 fire stations covering an area of 111 square miles including the Salt Lake International Airport

Response Times MM:SS, 90% Fractile
Before 04:39, 07:15
After 04:37, 07:20

Resuscitation Not Attempted

	All Cases	DNAR	Obviously dead	Signs of Life
Before	588	17	571	0
After	650	35	615	0

Rhythm	Before	After
VF	66	101
VT	6	3
PEA	70	77
ASYS	134	140
AED Non-shockable	23	52
AED Shockable	30	32
Not Recorded	1	2

Location

	Home	Public	Rec	Nursing	Street	Transport	Other	Unknown
Before	222	26	0	22	23	10	18	7
After	231	52	3	28	47	16	22	2

Patient

	Age n; mean+SD	Sex Male	Female
Before	59 +19	214	116
After	57 +21	282	125

Witnessed

	Bystander	EMS	Unwitnessed	Unknown
Before	128	27	160	15
After	177	27	201	2

Bystander Response

	Bystander CPR					Bystander AED
	No bCPR	bCPR	CC Only	CC/Vent	Unknown	Shock
Before	190	140	2	71	67	11
After	202	205	120	38	47	19

Etiology

	Presumed Cardiac	Respiratory	Overdose	Not Recorded
Before	276	29	24	0
After	272	56	56	3

EMS Process

	First Defib Time mm:ss	Targeted Temp Control Intra-arrest	Unknown	Drugs Given
Before	09:26	0	2	285
After	10:05	288	4	379

Hospital Process

	Reperfusion Indicated/Done	Unknown	Targeted Temp Control Indicated/Done	Unknown
Before	48/31	3	37/22	10
After	65/54	0	44/28	10

Patient Outcomes Reporting Population

		Any ROSC		Survived Event		Survival DC	Fav neurological DC CPC <2
		Yes	Unknown	Yes	Unknown	Yes	Yes
EMS witnessed included	All EMS Treated Arrests	Before 100 / After 179	Before 1 / After 1	Before 99 / After 156	Before 1 / After 1	Before 36 / After 71	Before 25 / After 65
EMS witnessed excluded	Shockable bystander witnessed	Before 28 / After 60	Before 1 / After 0	Before 26 / After 56	Before 1 / After 0	Before 17 / After 38	Before 13 / After 34
	Shockable bystander CPR	Before 23 / After 52	Before 1 / After 0	Before 22 / After 47	Before 1 / After 0	Before 16 / After 31	Before 13 / After 29
	Non-shockable witnessed	Before 29 / After 57	Before 0 / After 0	Before 28 / After 53	Before 0 / After 0	Before 6 / After 16	Before 5 / After 15

Figure 1. Raw numbers presented in Utstein template format prior to and following the introduction of a system-wide effort to improve survival from out-of-hospital cardiac arrest in Salt Lake City. AED indicates automated external defibrillator; ASYS, asystole; BLS, Basic Life Support; CPC, Cerebral Performance Category; CPR, cardiopulmonary resuscitation; DNAR, Do not attempt resuscitation; EMS, emergency medical services; MM:SS, Minutes:Seconds; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; VF, ventricular fibrillation; VT, ventricular tachycardia.

ward. Previously, standard call and response clearance of the victim before defibrillation was the norm. No delay in initial defibrillation was prescribed. Furthermore, routine pulse checks were eliminated in favor of selective pulse checks when an organized rhythm was seen with a ventricular rate >40 beats/min and an end-tidal CO_2 value of >20 mm Hg was obtained. Any pause in CPR for a pulse check initiated a 10-second countdown by the rescuer performing chest compressions, and CPR was resumed automatically unless a declaration that a pulse had been detected was made. Previously, the lead paramedic dictated the frequency and duration of CPR pauses for rhythm and pulse checks.

d. On-scene resuscitation (versus early transport) was encouraged to avoid interruptions in CPR attributable to patient transfers/transport. Consistent with the indeterminate evidence regarding duration of resuscitative efforts, no upper time limit was given for field attempts, but it was suggested that at least 30 minutes of resuscitation be made and that efforts should continue, or the patient be transported if, after field efforts, good prognostic signs were present. Positive prognostic signs were considered to be an end-tidal CO_2 >20 mm Hg with an organized rhythm, persistent or recurrent ventricular fibrillation, witnessed arrest, or bystander CPR. Online medical control was obtained via a local emergency physician who was involved in all decisions to cease resuscitation efforts in the field. Paramedics were instructed to limit time spent on scene and transport pulseless victims early in select cases. Select cases were defined as patients who were clinically gravid, hypothermia was the cause of arrest, the victim was a pediatric patient, or there was an unstable or unsafe scene. Previously, EMS crews transported nearly all patients to the hospital after 15 to 20 minutes of on-scene attempts.

e. To help focus crews' early resuscitative efforts on CPR and defibrillation, passive oxygenation via non-rebreather mask was administered for the first 6 to 8 minutes for all adult witnessed arrests of presumed cardiac etiology while initial CPR and defibrillation attempts were made.[28] Asynchronous ventilation via bag-valve mask was performed during resuscitations for all unwitnessed, pediatric,[36] and respiratory arrests. Following the prescribed period of passive ventilation (or bag-valve mask), paramedics were instructed to blindly insert a supraglottic airway (King LT®; Kingsystems) without pausing CPR. Previously, paramedics performed multiple intubation attempts via direct laryngoscopy on both adult and pediatric victims early in the resuscitation. In July 2013, video laryngoscopy with channel guided endotracheal tube placement during ongoing CPR replaced the supraglottic airway as the initial airway of choice in adults. The supraglottic airway device was reserved as a backup airway from that time forward.

f. In July 2013, an impedance threshold device was added to the advanced airway (ResQPod®; Advanced Circulatory Systems) to augment negative intrathoracic pressure during the release phase of chest compressions.

2. Simplified Medication Algorithm Adopted

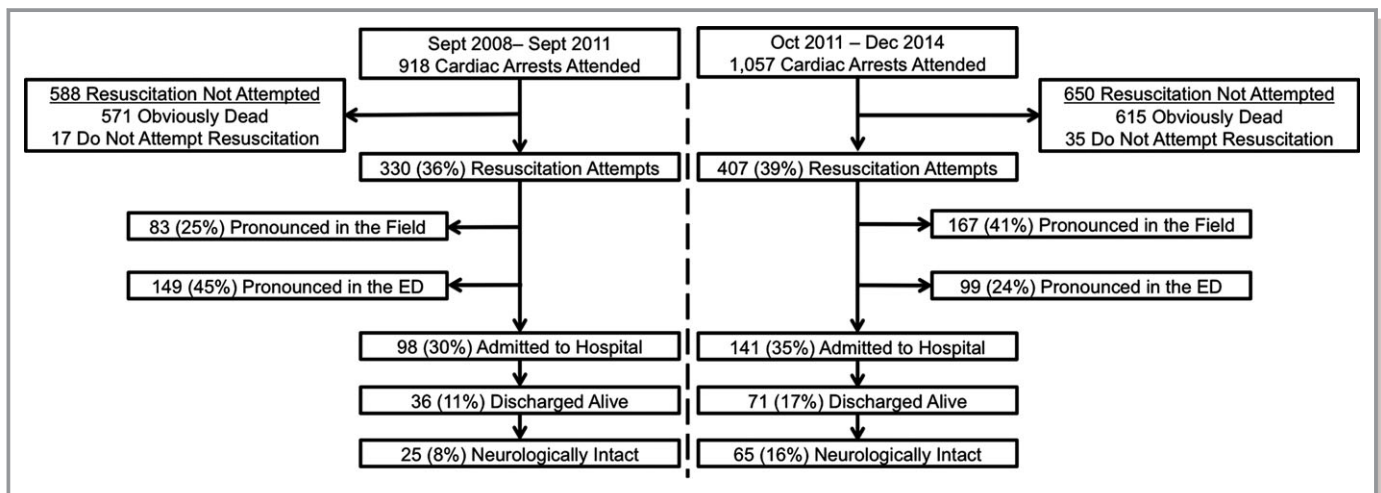a. As advised by 2010 AHA guidelines, atropine was removed as a treatment option for patients in

Figure 2. Flow diagram demonstrating the survival from cardiac arrest prior to and following the introduction of a system-wide effort to improve survival from out-of-hospital cardiac arrest in Salt Lake City. ED indicate emergency department.

Table 1. Baseline and Resuscitation Demographics Among Cardiac Arrest Victims Treated by the Salt Lake City Fire Department Before and After a Systemwide Intervention to Improve Survival

Variable	Before (n=330)	After (n=407)	P Value
Age, y ±SD	59±19	57±21	0.19
Male sex, No.	214 (65%)	282 (69%)	0.24
Initial shockable rhythm, No.	102 (31%)	136 (33%)	0.47
Arrest witnessed, No.	155 (47%)	204 (50%)	0.39
Bystander CPR performed, No.	140 (42%)	205 (50%)	0.03
Field return of spontaneous circulation, No.	100 (30%)	179 (44%)	0.0001

pulseless electrical activity and asystole. Amiodarone replaced lidocaine as the antiarrhythmic for recurrent or refractory ventricular fibrillation.

b. To minimize intravenous start times, first line access was obtained with an intraosseous needle placed in the proximal tibia (EZ-IO®; VidaCare Corp). Intra-arrest

hypothermia was initiated with chilled saline at 34°F administered as a medication flush fluid (to a maximum volume of 1 L). If return of spontaneous circulation (ROSC) was achieved, cooling was augmented with ice packs to the patient's groin and axilla.

3. EMS Crew Team Training

a. Resuscitation team dynamics were modeled on so-called pit crew principles, so named after Formula One pit crews, whose team members use a highly choreographed approach to task completion in parallel with virtual autonomy. In resuscitation, this approach assigns crew members to discrete therapeutic tasks that are performed without specific direction from a team leader. Dedicated tasks included airway management, CPR delivery, monitoring and defibrillation, medication administration, and documentation. Positions were assigned before scene arrival and a prespecified location at the side of the victim was prescribed for each crew member. Before implementation, a lead paramedic called out each intervention as desired.

Table 2. Comparison of Utstein Process Variables Before and After a Systemwide Intervention to Improve Survival

Utstein Process Variable	Before (n=330)	After (n=407)	P Value
PSAP call to dispatch time, s (IQR)*	85 (64 to 116)	96 (68 to 133)	0.0002
EMS response time, MM:SS (90% fractile)[†]	04:39 (07:15)	04:37 (07:20)	0.41
Call to defibrillation time, min (IQR)[‡]	9.4 (7.4 to 12.0)	10.1 (7.3 to 13.0)	0.40
Prehospital hypothermia, No.	6 (2%)	288 (71%)	<0.0001
First advanced airway attempted, No.			
None	52 (16%)	64 (16%)	0.84
Endotracheal intubation	267 (81%)	237 (58%)	<0.0001
King LT	10 (3%)	93 (23%)	<0.0001
Doses of epinephrine administered, No. (IQR)	2 (1 to 3)	3 (2 to 3)	<0.0001
Doses of atropine administered, No. (IQR)	1 (0 to 2)	0 (0 to 0)	<0.0001
Chest compression fraction, No. (IQR)	Not measured	0.92 (0.89 to 0.94)	NA
Compression rate, compressions per minute (IQR)	Not measured	114 (107 to 122)	NA
Compression depth, cm (IQR)	Not measured	5.5 (4.8 to 6.1)	NA
Preshock pause, s (IQR)	Not measured	2 (0 to 8)	NA
Field 12-lead ECG obtained after ROSC, No.	0/100 (0%)	40/179 (22%)	<0.0001
Hospital postarrest care, No.			
Diagnostic angiography[§]	31/48 (65%)	54/65 (83%)	0.03
Targeted temperature management[‖]	22/37 (59%)	28/44 (64%)	0.90

EMS indicates emergency medical services; PSAP, public safety access point; ROSC, return of spontaneous circulation.
*PSAP (911 in the United States).
[†]Emergency 911 call to arrival of EMS on scene.
[‡]Among victims with an initially shockable rhythm shocked first by EMS (excludes public access defibrillation).
[§]Evaluated among patients with an initial shockable rhythm who survived to hospital admission (missing for 3 patients in the before group).
[‖]Evaluated among patients with an initial shockable rhythm admitted to the hospital who had an advanced airway placed in the prehospital setting (missing for 10 patients in each group).

b.   All personnel underwent live didactic and offline video training on the updated protocols and performed hands-on simulated resuscitations using mannequins, supervised by the medical director and medical division officers. The pit crew approach and new protocol were reemphasized in March 2012, July 2013, and May 2014.

Data Collection

Patient characteristics and out-of hospital interventions were obtained from the EMS ePCR and entered into an internal Utstein style database (REDCap™ electronic data capture tools hosted at the University of Utah). Hospital outcomes were obtained from the patient's discharge summary and correspondence with a registered nurse liaison at each ST-elevation myocardial infarction receiving center. Neurological outcomes were estimated by using the Cerebral Performance Category (CPC) scale, which is reported by the receiving hospital.[37] A CPC score of 1 or 2 was considered neurologically intact for this analysis.

Statistical Analysis

The principal outcome of this study was the change in proportion, if any, in neurologically intact survival between the preintervention and postintervention phases. Specifically, proportions achieving functional survival (CPC 1 or 2) during the period between September 1, 2008, when the SLCFD adopted its electronic patient care record system, through September 30, 2011, when the systemwide protocol was adopted, were compared with the postintervention period between October 1,
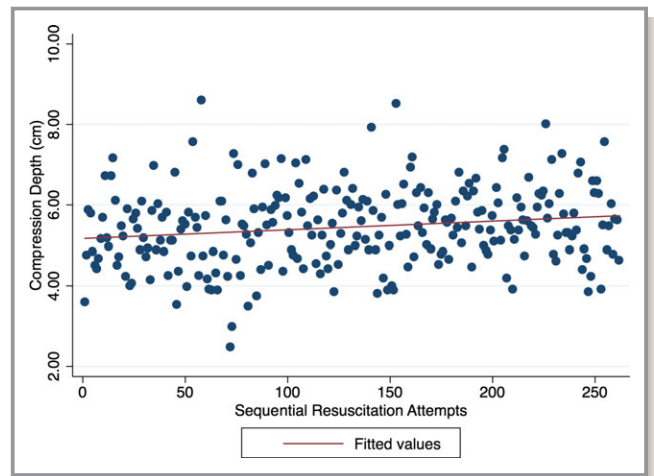

Figure 4. Scatter plot and linear regression line demonstrating the change in compression depth over time following the initiation of real time and offline CPR feedback in Salt Lake City, Utah (p=0.006 for slope of regression line).

2011, and December 31, 2014. Results were analyzed using STATA/IC 12.1 for Mac (StataCorp). Differences between proportions and continuous variables were tested by using the STATA commands *prtesti* and *ranksum*, respectively. Changes in CPR depth, rate, and CCF over time were analyzed by using least squares linear regression. Multivariable logistic regression was used to test the association between the intervention and neurologically intact survival while controlling for age and sex, initial shockable rhythm, whether the patient was a witnessed arrest, and whether bystander CPR was administered. A 2-sided value of $P<0.05$ was considered to be statistically significant.
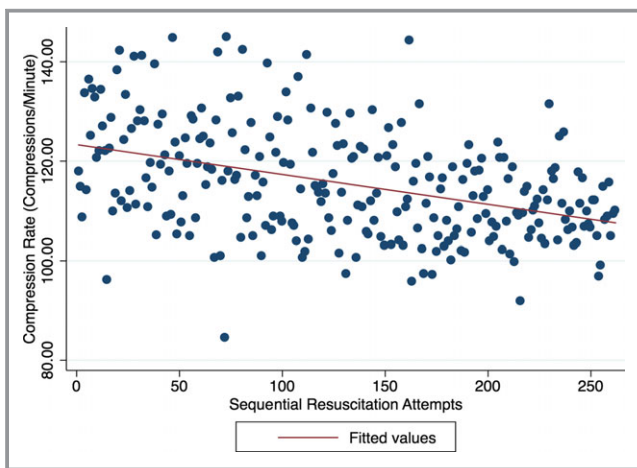

Figure 3. Scatter plot and linear regression line demonstrating the change in compression rate over time following the initiation of real time and offline CPR feedback in Salt Lake City, Utah (p<0.0001 for slope of regression line).
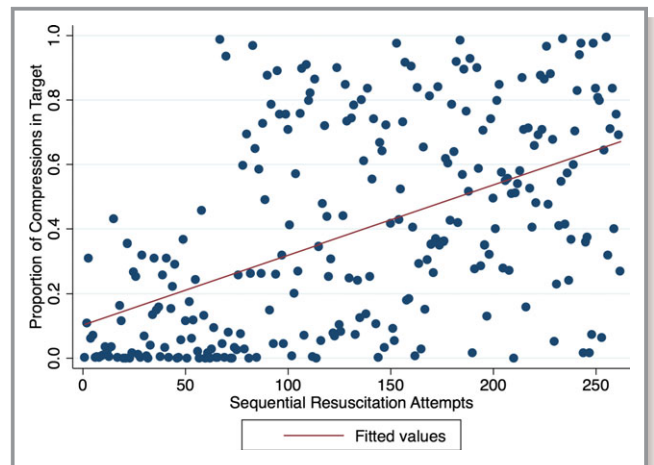

Figure 5. Scatter plot and linear regression line demonstrating the change in the proportion of chest compressions meeting American Heart Association targets for both depth and rate per resuscitation attempt over time following the initiation of real-time and offline cardiopulmonary resuscitation feedback in Salt Lake City, Utah ($P<0.0001$ for slope of regression line).

Table 3. Multivariate Logistic Regression Testing the Association Between Implementation of a Systemwide Protocol to Improve Cardiac Arrest Survival and Neurologically Intact Survival From Cardiac Arrest

Variable	Adjusted Odds Ratio	95% CI	P Value
New protocol	2.3	1.3 to 4.0	0.005
Witnessed arrest	7.0	3.4 to 14.6	<0.0001
Initial shockable rhythm	4.9	2.8 to 8.5	<0.0001
Bystander CPR	2.6	1.5 to 4.5	0.001
Age (per year of life)	0.98	0.97 to 0.99	0.005
Male sex	0.73	0.42 to 1.28	0.28

Results

Between September 1, 2008, and September 30, 2011, SLCFD EMS personnel attended 918 cardiac arrests, attempting resuscitation in 330 (36%), resulting in 25 neurologically intact survivors (8%). Post protocol implementation (October 1, 2011, to September 2014), EMS personnel attended 1057 cardiac arrests, of which 407 (39%) resuscitations were attempted, resulting in 65 neurologically intact survivors (16%). The proportion of cases in which resuscitation was attempted was not statistically different between periods ($P=0.24$). The unadjusted increase in overall functional survival between periods was 8.4% (95% CI 3.8% to 13.0%, $P=0.0005$). The number needed to treat to gain an additional

neurologically intact survivor using the new protocol was 12. The Utstein template for the time periods of interest is given in Figure 1. For a CONSORT style flow diagram, see Figure 2.

Patient demographics and resuscitation variables were similar between groups with the exception of bystander CPR and ROSC in the field, which were both higher in the postintervention period (Table 1). Among attempted resuscitations, there were 20 (5%) of 407 and 10 (3%) of 330 pediatric victims in the postintervention and preintervention period, respectively. Field pronouncement was higher in the postintervention period (167 [41%] versus 83 [25%], $P<0.0001$).

Selected Utstein process information is presented in Table 2. Response times and defibrillation times were similar between periods. In the postintervention period, paramedics administered more epinephrine, consistent with longer on-scene resuscitation efforts. The reduction in atropine administration corresponded with the removal of this drug from 2010 guidelines. Rates of in-hospital postarrest targeted temperature management were similar in both periods. Among patients with an initial shockable rhythm who survived to hospital admission, postarrest diagnostic angiography was higher in the postintervention period, 54 (83%) of 65 versus 31 (65%) of 48 ($P=0.03$), consistent with the revised destination criteria.

CPR quality measures were also examined. CCF did not change in a statistically significant fashion over time ($P=0.8$); however, CPR rate decreased significantly (Figure 3, $P<0.0001$ for slope) and depth increased (Figure 4,
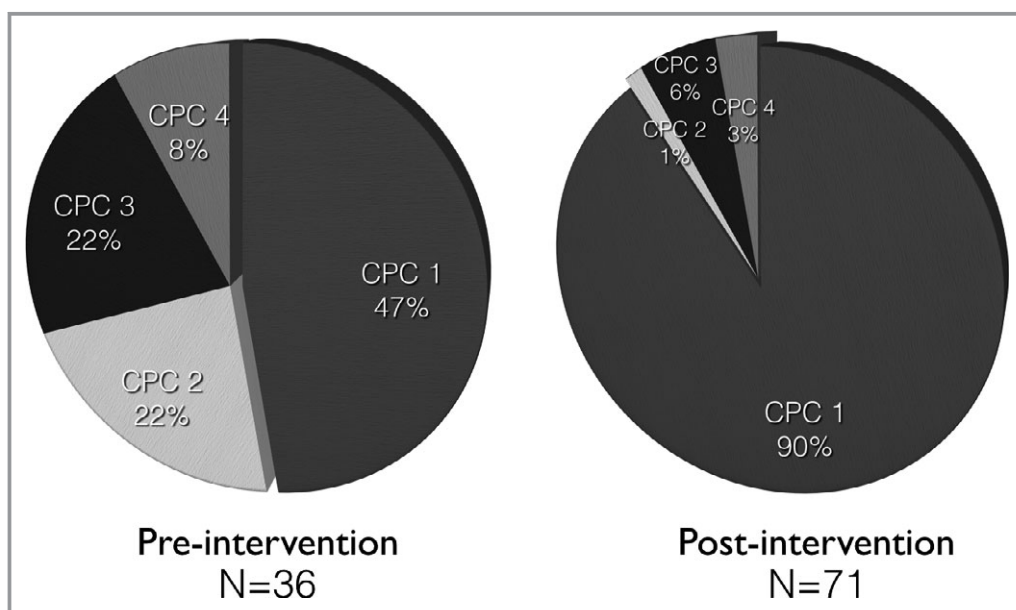

Figure 6. Distribution of CPC scores at hospital discharge between patients prior to and following the introduction of a system-wide effort to improve survival from out-of-hospital cardiac arrest in Salt Lake City. CPC indicate cerebral performance category.

P=0.006 for slope). Further, there was a significant increase in the proportion of chest compressions/resuscitation attempts that were within AHA guidelines for both rate and depth over time (Figure 5, P<0.0001 for slope).

Field ROSC was achieved in 179 (44%) of 407 in the postintervention period compared with 100 (30%) of 330 in the preintervention period (P<0.0001). Survival to hospital admission was also higher postintervention, but the differences were not statistically significant (141 [35%] versus 98 [30%], P=0.15). However, for patients who survived to hospital admission, a higher proportion in the postintervention period survived to hospital discharge (71/141 [50%] versus 36/98 [37%], P=0.037) and had a favorable neurological outcome (65 [46%] versus 25 [26%], P=0.0005) compared with patients treated before protocol changes. Additionally, neurologically intact survival was higher among Utstein criteria victims in the postintervention period. This was defined as witnessed arrests with an initial shockable rhythm (38/97 [39%] versus 15/70 [21%], P=0.015).

The univariate odds ratio for the association between neurologically intact survival (CPC categories 1 and 2) and protocol implementation was 2.3 (95% CI 1.4 to 3.7, P=0.001) and was unchanged after controlling for Utstein variables (Table 3). Among discharged patients, the distribution of CPC scores was more favorable in the postintervention period (P<0.0001), as demonstrated in Figure 6.

Discussion

The implementation of several protocol changes, including several AHA best practice recommendations for EMS resuscitation of OHCA patients, improved patient outcomes in Salt Lake City, Utah. Specifically, systemwide EMS initiatives focused on high-quality and minimally interrupted CPR, prolonged scene efforts, preassignment of specified interventions (pit crew model), improved physician oversight, and the transport of OHCA patients with ROSC to ST-elevation myocardial infarction receiving centers. Many of these practices were selected for implementation because they have been associated with both improved patient survival to hospital discharge and favorable neurological outcome in other systems.[11,26–28,33,38,39]

Because multiple interventions were simultaneously adopted in an attempt to improve care, it is impossible to identify the components responsible for the observed increase in survival. However, given the historical importance of BLS-level interventions, improvements in the quality of CPR and rapid defibrillation are most likely to impact cardiac arrest survival. Coordination of tasks and minimization of CPR interruption have been shown in the past to improve CPR performance.[11,40–42] Another vital addition to the process was timely feedback to the EMS crews regarding the codes in which they participated. Directed feedback has been show to be instrumental in helping EMS crews with process improvement measures.[14,34,35,43] We measured significant improvements in compliance with AHA guideline–based targets for CPR metrics over time through the use of both real-time and offline CPR feedback. Over sequential resuscitation attempts, compression depth increased, compression rate decreased, and the proportion of chest compressions achieving both target rate and depth also increased.

Following protocol implementation, providers more frequently remained on-scene to work the resuscitation to ROSC or field termination. Remaining on-scene until EMS crews obtain either ROSC or exhaustion of efforts avoids the interruptions in CPR inherent to scene removal and transport of OHCA victims.[11,44,45] Moreover, the emergency department has historically lacked therapies for OHCA not already available in the field. Exchanging a highly organized pit crew resuscitation for what is an often a chaotic resuscitation effort in the emergency department seems unwise in most cases.

Improvements in post–cardiac arrest care at receiving hospitals are also a likely contributor to improved outcomes. Regionalization of post cardiac care has been associated with improved patient outcomes in other systems.[38,39] During the postintervention period, patients were preferentially taken to dedicated ST-elevation myocardial infarction receiving centers that had protocolized care for postarrest patients, including targeted temperature management and percutaneous coronary intervention. Consistent with these changes, postarrest coronary intervention increased in the postintervention period.

Limitations

While interventional, this study used a before-and-after analytic design, which may have been affected by temporal trends in OHCA survival. Additionally, multiple interventions were undertaken at once, and thus, the impact of individual changes to protocol cannot be measured. It is possible, for example, that improvements in outcome were largely due to improved hospital-based care. While this would not account for the increase in field ROSC observed, it may speak to the importance of EMS protocols that designate transport of the post–cardiac arrest victim exclusively to destination hospitals capable of performing 24-hour coronary intervention and targeted temperature management. Additionally, while the implementation of this protocol in a single, urban municipality led to local improvements in survival from OHCA, whether such a protocol is generalizable to other communities is uncertain at this time.

Conclusions

A multifaceted approach to improving OHCA resuscitation that focused on the inclusion of several AHA best practices for EMS

care of OHCA patients was associated with improved survival and neurological outcome for patients in Salt Lake City, Utah.

Disclosures

Dr Youngquist reports modest speaking honorarium from Physio–Control, Corp. No other potential conflicts of interest. The authors alone are responsible for the content and writing of the manuscript.

References

1. Nichol G, Thomas E, Callaway CW, Hedges J, Powell JL, Aufderheide TP, Rea T, Lowe R, Brown T, Dreyer J, Davis D, Idris A, Stiell I; Resuscitation Outcomes Consortium Investigators. Regional variation in out-of-hospital cardiac arrest incidence and outcome [published correction appears in JAMA. 2008;300:1763]. *JAMA*. 2008;300:1423–1431.

2. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Borden WB, Bravata DM, Dai S, Ford ES, Fox CS, Franco S, Fullerton HJ, Gillespie C, Hailpern SM, Heit JA, Howard VJ, Huffman MD, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Magid D, Marcus GM, Marelli A, Matchar DB, McGuire DK, Mohler ER, Moy CS, Mussolino ME, Nichol G, Paynter NP, Schreiner PJ, Sorlie PD, Stein J, Turan TN, Virani SS, Wong ND, Woo D, Turner MB; American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics–2013 update: a report from the American Heart Association [published correction appears in Circulation. 2013;127: doi:10.1161/CIR.0b013e31828124ad]. *Circulation*. 2013;127:e6–e245.

3. Merchant RM, Yang L, Becker LB, Berg RA, Nadkarni V, Nichol G, Carr BG, Mitra N, Bradley SM, Abella BS, Groeneveld PW; American Heart Association Get With The Guidelines-Resuscitation Investigators. Incidence of treated cardiac arrest in hospitalized patients in the United States. *Crit Care Med*. 2011;39:2401–2406.

4. McNally B, Robb R, Mehta M, Vellano K, Valderrama AL, Yoon PW, Sasson C, Crouch A, Perez AB, Merritt R, Kellermann A. Out-of-hospital cardiac arrest surveillance—Cardiac Arrest Registry to Enhance Survival (CARES), United States, October 1, 2005 – December 31, 2010. *MMWR Surveill Summ*. 2011;60:1–19.

5. Sasson C, Rogers MA, Dahl J, Kellermann AL. Predictors of survival from out-of-hospital cardiac arrest: a systematic review and meta-analysis. *Circ Cardiovasc Qual Outcomes*. 2010;3:63–81.

6. Fredriksson M, Herlitz J, Nichol G. Variation in outcome in studies of out-of-hospital cardiac arrest: a review of studies conforming to the Utstein guidelines. *Am J Emerg Med*. 2003;21:276–281.

7. Nichol G, Aufderheide TP, Eigel B, Neumar RW, Lurie KG, Bufalino VJ, Callaway CW, Menon V, Bass RR, Abella BS, Sayre M, Dougherty CM, Racht EM, Kleinman ME, O'Connor RE, Reilly JP, Ossmann EW, Peterson E; American Heart Association Emergency Cardiovascular Care Committee; Council on Arteriosclerosis, Thrombosis, and Vascular Biology; Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation; Council on Cardiovascular Nursing; Council on Clinical Cardiology; Advocacy Committee; Council on Quality of Care and Outcomes Research. Regional systems of care for out-of-hospital cardiac arrest: a policy statement from the American Heart Association [published correction appears in Circulation. 2010;122:e439]. *Circulation*. 2010;121:709–729.

8. Abella BS, Sandbo N, Vassilatos P, Alvarado JP, O'Hearn N, Wigder HN, Hoffman P, Tynus K, Vanden Hoek TL, Becker LB. Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. *Circulation*. 2005;111:428–434.

9. Idris AH, Guffey D, Aufderheide TP, Brown S, Morrison LJ, Nichols P, Powell J, Daya M, Bigham BL, Atkins DL, Berg R, Davis D, Stiell I, Sopko G, Nichol G; Resuscitation Outcomes Consortium (ROC) Investigators. Relationship between chest compression rates and outcomes from cardiac arrest. *Circulation*. 2012;125:3004–3012.

10. Hazinski MF, Nolan JP, Billi JE, Böttiger BW, Bossaert L, de Caen AR, Deakin CD, Drajer S, Eigel B, Hickey RW, Jacobs I, Kleinman ME, Kloeck W, Koster RW, Lim SH, Mancini ME, Montgomery WH, Morley PT, Morrison LJ, Nadkarni VM, O'Connor RE, Okada K, Perlman JM, Sayre MR, Shuster M, Soar J, Sunde K, Travers AH, Wyllie J, Zideman D. Part 1: executive summary: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*. 2010;122:S250–S275.

11. Meaney PA, Bobrow BJ, Mancini ME, Christenson J, Caen AR, Bhanji F, Abella BS, Kleinman ME, Edelson DP, Berg RA, Aufderheide TP, Menon V, Leary M; CPR Quality Summit Investigators, the American Heart Association Emergency Cardiovascular Care Committee, and the Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation. Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. *Circulation*. 2013;128:417–435.

12. Travers AH, Rea TD, Bobrow BJ, Edelson DP, Berg RA, Sayre MR, Berg MD, Chameides L, O'Connor RE, Swor RA. Part 4: CPR overview: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S676–S684.

13. Berg RA, Hemphill R, Abella BS, Aufderheide TP, Cave DM, Hazinski MF, Lerner EB, Rea TD, Sayre MR, Swor RA. Part 5: adult basic life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care [published correction appears in Circulation. 2011;124:e402]. *Circulation*. 2010;122:S685–S705.

14. Edelson DP, Litzinger B, Arora V, Walsh D, Kim S, Lauderdale DS, Vanden Hoek TL, Becker LB, Abella BS. Improving in-hospital cardiac arrest process and outcomes with performance debriefing. *Arch Intern Med*. 2008;168:1063–1069.

15. Edelson DP, Abella BS, Kramer-Johansen J, Wik L, Myklebust H, Barry AM, Merchant RM, Hoek TL, Steen PA, Becker LB. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. *Resuscitation*. 2006;71:137–145.

16. Kramer-Johansen J, Myklebust H, Wik L, Fellows B, Svensson L, Sørebø H, Steen PA. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. *Resuscitation*. 2006;71:283–292.

17. Babbs CF, Kemeny AE, Quan W, Freeman G. A new paradigm for human resuscitation research using intelligent devices. *Resuscitation*. 2008;77:306–315.

18. Stiell IG, Brown SP, Christenson J, Cheskes S, Nichol G, Powell J, Bigham B, Morrison LJ, Larsen J, Hess E, Vaillancourt C, Davis DP, Callaway CW; Resuscitation Outcomes Consortium (ROC) Investigators. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? *Crit Care Med*. 2012;40:1192–1198.

19. Zuercher M, Hilwig RW, Ranger-Moore J, Nysaether J, Nadkarni VM, Berg MD, Kern KB, Sutton R, Berg RA. Leaning during chest compressions impairs cardiac output and left ventricular myocardial blood flow in piglet cardiac arrest. *Crit Care Med*. 2010;38:1141–1146.

20. Wik L, Kramer-Johansen J, Myklebust H, Sørebø H, Svensson L, Fellows B, Steen PA. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA*. 2005;293:299–304.

21. Aufderheide TP, Sigurdsson G, Pirrallo RG, Yannopoulos D, McKnite S, von Briesen C, Sparks CW, Conrad CJ, Provo TA, Lurie KG. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. *Circulation*. 2004;109:1960–1965.

22. Milander MM, Hiscok PS, Sanders AB, Kern KB, Berg RA, Ewy GA. Chest compression and ventilation rates during cardiopulmonary resuscitation: the effects of audible tone guidance. *Acad Emerg Med*. 1995;2:708–713.

23. Valenzuela TD, Kern KB, Clark LL, Berg RA, Berg MD, Berg DD, Hilwig RW, Otto CW, Newburn D, Ewy GA. Interruptions of chest compressions during emergency medical systems resuscitation. *Circulation*. 2005;112:1259–1265.

24. Christenson J, Andrusiek D, Everson-Stewart S, Kudenchuk P, Hostler D, Powell J, Callaway CW, Bishop D, Vaillancourt C, Davis D, Aufderheide TP, Idris A, Stouffer JA, Stiell I, Berg R; Resuscitation Outcomes Consortium Investigators. Chest compression fraction determines survival in patients with out-of-hospital ventricular fibrillation. *Circulation*. 2009;120:1241–1247.

25. Cheskes S, Schmicker RH, Christenson J, Salcido DD, Rea T, Powell J, Edelson DP, Sell R, May S, Menegazzi JJ, Van Ottingham L, Olsufka M, Pennington S, Simonini J, Berg RA, Stiell I, Idris A, Bigham B, Morrison L; Resuscitation Outcomes Consortium (ROC) Investigators. Perishock pause: an independent predictor of survival from out-of-hospital shockable cardiac arrest. *Circulation*. 2011;124:58–66.

26. Rea TD, Helbock M, Perry S, Garcia M, Cloyd D, Becker L, Eisenberg M. Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest: survival implications of guideline changes. *Circulation*. 2006;114:2760–2765.

27. Hinchey PR, Myers JB, Lewis R, De Maio VJ, Reyer E, Licatese D, Zalkin J, Snyder G. Improved out-of-hospital cardiac arrest survival after the sequential implementation of 2005 AHA guidelines for compressions, ventilations, and induced hypothermia: the Wake county experience. *Ann Emerg Med*. 2010;56:348–357.

28. Bobrow BJ, Clark LL, Ewy GA, Chikani V, Sanders AB, Berg RA, Richman PB, Kern KB. Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. *JAMA*. 2008;299:1158–1165.

29. Vadeboncoeur T, Stolz U, Panchal A, Silver A, Venuti M, Tobin J, Smith G, Nunez M, Karamooz M, Spaite D, Bobrow B. Chest compression depth and survival in out-of-hospital cardiac arrest. *Resuscitation*. 2014;85:182–186.

30. Stiell IG, Brown SP, Nichol G, Cheskes S, Vaillancourt C, Callaway CW, Morrison LJ, Christenson J, Aufderheide TP, Davis DP, Free C, Hostler D, Stouffer JA, Idris AH; Resuscitation Outcomes Consortium Investigators. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? *Circulation*. 2014;130:1962–1970.

31. Bobrow BJ, Spaite DW, Berg RA, Stolz U, Sanders AB, Kern KB, Vadeboncoeur TF, Clark LL, Gallagher JV, Stapczynski JS, LoVecchio F, Mullins TJ, Humble WO, Ewy GA. Chest compression–only CPR by lay rescuers and survival from out-of-hospital cardiac arrest. *JAMA*. 2010;304:1447–1454.

32. Bobrow BJ, Ewy GA, Clark L, Chikani V, Berg RA, Sanders AB, Vadeboncoeur TF, Hilwig RW, Kern KB. Passive oxygen insufflation is superior to bag-valve-mask ventilation for witnessed ventricular fibrillation out-of-hospital cardiac arrest. *Ann Emerg Med*. 2009;54:656–662.

33. Garza AG, Gratton MC, Salomone JA, Lindholm D, McElroy J, Archer R. Improved patient survival using a modified resuscitation protocol for out-of-hospital cardiac arrest. *Circulation*. 2009;119:2597–2605.

34. Fischer H, Neuhold S, Hochbrugger E, Steinlechner B, Koinig H, Milosevic L, Havel C, Frantal S, Greif R. Quality of resuscitation: flight attendants in an airplane simulator use a new mechanical resuscitation device: a randomized simulation study. *Resuscitation*. 2011;82:459–463.

35. Zebuhr C, Sutton RM, Morrison W, Niles D, Boyle L, Nishisaki A, Meaney P, Leffelman J, Berg RA, Nadkarni VM. Evaluation of quantitative debriefing after pediatric cardiac arrest. *Resuscitation*. 2012;83:1124–1128.

36. Gausche M, Lewis RJ, Stratton SJ, Haynes BE, Gunter CS, Goodrich SM, Poore PD, McCollough MD, Henderson DP, Pratt FD, Seidel JS. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: a controlled clinical trial. *JAMA*. 2000;283:783–790.

37. Safar P. Resuscitation after brain ischemia. In: Grenvik A, Safar P, eds. *Brain Failure and Resuscitation*. New York, NY: Churchill Livingstone; 1981:155–184.

38. Spaite DW, Bobrow BJ, Stolz U, Berg RA, Sanders AB, Kern KB, Chikani V, Humble W, Mullins T, Strapczynski JS, Ewy GA; Arizona Cardiac Receiving Center Consortium. Statewide regionalization of postarrest care for out-of-hospital cardiac arrest: association with survival and neurologic outcome. *Ann Emerg Med*. 2014;64:496–506.

39. Peberdy MA, Callaway CW, Neumar RW, Geocadin RG, Zimmerman JL, Donnino M, Gabrielli A, Silvers SM, Zaritsky AL, Merchant R, Vanden Hoek TL, Kronick SL. Part 9: post–cardiac arrest care: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122:S768–S786.

40. Yeung JH, Ong GJ, Davies RP, Gao F, Perkins GD. Factors affecting team leadership skills and their relationship with quality of cardiopulmonary resuscitation. *Crit Care Med*. 2012;40:2617–2621.

41. Hunziker S, Bühlmann C, Tschan F, Balestra G, Legeret C, Schumacher C, Semmer NK, Hunziker P, Marsch S. Brief leadership instructions improve cardiopulmonary resuscitation in a high-fidelity simulation: a randomized controlled trial. *Crit Care Med*. 2010;38:1086–1091.

42. Cooper S, Wakelam A. Leadership of resuscitation teams: "Lighthouse Leadership". *Resuscitation*. 1999;42:27–45.

43. Bobrow BJ, Vadeboncoeur TF, Stolz U, Silver AE, Tobin JM, Crawford SA, Mason TK, Schirmer J, Smith GA, Spaite DW. 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. *Ann Emerg Med*. 2013;62:47–56.

44. Havel C, Schreiber W, Riedmuller E, Haugk M, Richling N, Trimmel H, Malzer R, Sterz F, Herkner H. Quality of closed chest compression in ambulance vehicles, flying helicopters and at the scene. *Resuscitation*. 2007;73:264–270.

45. Olasveengen TM, Wik L, Steen PA. Quality of cardiopulmonary resuscitation before and during transport in out-of-hospital cardiac arrest. *Resuscitation*. 2008;76:185–190.