

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

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Study objective: We assess survival from out-of-hospital cardiac arrest after community-wide implementation of 2005 American Heart Association guidelines.

Methods: This was an observational multiphase before-after cohort in an urban/suburban community (population 840,000) with existing advanced life support. Included were all adults treated for cardiac arrest by emergency responders. Excluded were patients younger than 16 years and trauma patients. Intervention phases in months were baseline 16; phase 1, new cardiopulmonary resuscitation 12; phase 2, impedance threshold device 6; and phase 3, full implementation including out-of-hospital-induced hypothermia 12. Primary outcome was survival to discharge. Other survival and neurologic outcomes were compared between study phases, and adjusted odds ratios with 95% confidence intervals (CIs) for survival by phase were determined by multivariate regression.

Results: One thousand three hundred sixty-five cardiac arrest patients were eligible for inclusion: baseline n=425, phase 1 n=369, phase 2 n=161, phase 3 n=410. Across phases, patients had similar demographic, clinical, and emergency medical services characteristics. Overall and witnessed ventricular fibrillation and ventricular tachycardia survival improved throughout the study phases: respectively, baseline 4.2% and 13.8%, phase 1 7.3% and 23.9%, phase 2 8.1% and 34.6%, and phase 3 11.5% and 40.8%. The absolute increase for overall survival from baseline to full implementation was 7.3% (95% CI 3.7% to 10.9%); witnessed ventricular fibrillation/ventricular tachycardia survival was 27.0% (95% CI 13.6% to 40.4%), representing an additional 25 lives saved annually in this community.

Conclusion: In the context of a community-wide focus on resuscitation, the sequential implementation of 2005 American Heart Association guidelines for compressions, ventilations, and induced hypothermia significantly improved survival after cardiac arrest. Further study is required to clarify the relative contribution of each intervention to improved survival outcomes. [Ann Emerg Med. 2010;56:348-357.]

Please see page 349 for the Editor's Capsule Summary of this article.

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INTRODUCTION

Background

Out-of-hospital cardiac arrest is a global public health problem with a pattern of high incidence and variable rates of survival to hospital discharge, ranging from 1% to 20%.^{1,2} The strength of the community response, known as the American

Heart Association's (AHA's) "chain of survival" may account for higher survival rates in some communities.³⁻⁵

The chain of survival is a community approach to improving out-of-hospital cardiac arrest outcomes, comprising 4 links: (1) early recognition and access to emergency medical services (EMS), (2) early cardiopulmonary resuscitation (CPR), (3) early defibrillation, and (4) early advanced cardiac life support. Although early CPR and defibrillation are the only independent interventions proven to increase cardiac arrest survival, a

Editor's Capsule Summary

What is already known on this topic

2005 American Heart Association guidelines recommend chest compression before defibrillation for unwitnessed ventricular fibrillation/ventricular tachycardia, 1 shock versus 3, and postresuscitation hypothermia induction, whereas they deemphasize ventilations.

What question this study addressed

This 1,365-patient observational time series measured survival to hospital discharge in patients with out-of-hospital cardiac arrest during a tiered implementation of the 2005 guidelines.

What this study adds to our knowledge

In this urban/suburban emergency medical services system, there was a doubling of survival between the pre- and postimplementation phases.

How this might change clinical practice

This article provides support for the 2005 guidelines but should be confirmed in other systems and, ideally, with randomized trials.

community-wide approach incorporating elements from each “link” may substantially improve cardiac arrest outcomes.⁵⁻⁷

Importance

The AHA Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care were updated in 2005 to emphasize minimal interruption in chest compressions, strict control of ventilation rates to avoid hyperventilation, and induction of postresuscitation hypothermia to improve neurologic status for survivors.^{4,8-17} Adjuncts to assist with compression and ventilation quality, including mechanical CPR devices and the impedance threshold device, were also recommended.^{4,9,18-20} The impedance threshold device is an airway adjunct that purports to decrease intrathoracic pressure between ventilations (ie, it blocks air from entering the lungs during the decompression phase of CPR) and helps avoid hyperventilation through the use of a timing light.

Goals of This Investigation

Although each of the new recommendations has been studied independently, the effect of broad implementation at the community level is unknown.^{18,21-26} The primary objective of this study was to evaluate survival to hospital discharge from out-of-hospital cardiac arrest after community-wide implementation of the new guidelines in a large urban/suburban setting in North Carolina with an existing firefighter first-responder defibrillation program.

MATERIALS AND METHODS

Study Design

We performed an analysis of out-of-hospital and clinical data from a natural experiment occurring during 46 consecutive months, using a 4-phase “before-after” controlled design for all patients treated for out-of-hospital cardiac arrest. During the baseline phase (16 months), patients were treated according to 2000 AHA guidelines with 15:2 compression-ventilation ratios and a “stacked” sequence of up to 3 shocks, without interposed chest compressions.^{4,27} Emphases for phase 1, “new CPR,” (12 months), were minimal interruptions during chest compressions, single defibrillation, control of ventilation rates, and use of the intraosseous route for vascular access in adults. Early intubation was deemphasized. Emphases for phase 2 were use of the impedance threshold device, ventilation rates guided by timing light, and the concept of working cardiac arrests in the field until return of spontaneous circulation or obvious futility. Finally, at phase 3 (12 months), full implementation was achieved with the initiation of out-of-hospital hypothermia in eligible patients who had no purposeful movement after return of spontaneous circulation and had an initial tympanic temperature greater than 34°C (93.2°F). This intervention was in addition to those treatments implemented in phases 1 and 2.

Setting

Wake County, NC, is an urban/suburban community of approximately 840,000 residents. The EMS service receives more than 65,000 calls to 911 annually, including approximately 700 calls for suspected out-of-hospital cardiac arrest. The EMS system is composed of 75 emergency medical dispatchers, approximately 1,500 basic life support firefighter first responders, and 225 advanced life support (ALS) personnel. Emergency medical calls are processed by either of 2 public safety answering points and result in the dispatch of paramedic-level ambulances for all service requests. For high-acuity calls, including presumed cardiac arrest, a fire department first-responder apparatus and a paramedic supervisor vehicle are also dispatched.

Suspected cardiac arrest patients received a standardized, rapid response, including dispatch-assisted CPR instructions (Medical Priority Dispatch Systems). Both public safety answering points utilize processes for synchronization of their clocks to global positioning system time. All dispatchers, first responders, and ALS providers operate under uniform medical control, with all field-response staff receiving didactic and/or practical education for protocol updates before implementing the changes. This EMS system serves 7 hospitals that are affiliated with 3 health care systems. Two of the hospitals have 24-hour percutaneous coronary intervention capability. These 2 hospitals adopted a hypothermia protocol in addition to their long-standing percutaneous coronary intervention protocol for patients with ST-segment elevation myocardial infarction and were therefore designated as the only receiving hospitals for

resuscitated cardiac arrest patients during the full implementation phase (phase 3).

Selection of Participants

The study population included all patients with out-of-hospital cardiac arrests occurring within Wake County, NC. Patients included for analysis were aged at least 16 years and had received CPR by an EMS provider whether they were ultimately transported to the hospital or not; in other words, patients who experienced field termination of their resuscitation were included and, along with all transported patients, served as the population at risk in all phases of the study. Exclusion criteria included obvious death (strictly defined as the presence of rigor mortis or dependent lividity), traumatic arrest, patients with a valid do-not-resuscitate order presented to EMS personnel, and resuscitations in which extensive advanced cardiac life support (eg, defibrillation with multiple rounds of drugs) was administered by on-scene medical staff in their primary clinical setting before EMS was called (eg, physician/physician extender in a prison hospital). The study was approved for human studies exemption by the institutional review boards of WakeMed Health and Hospitals and Rex Healthcare in Raleigh, NC.

Interventions

Complete baseline out-of-hospital cardiac arrest data were available for the 16-month period preceding study interventions. A system-wide adoption of the 2005 AHA guidelines was implemented in a stepwise fashion during the following 2.5 years. Successive interventions were introduced during EMS protocol update sessions provided by the medical director. Protocol update sessions for all ALS providers in the EMS system were delivered during a 1-month period leading to a single date and time for simultaneous system-wide implementation of the new protocols. For the first such protocol change, phase 1, EMS personnel were instructed to interrupt compressions only to verify cardiac rhythm, provide defibrillations, or perform vital interventions.²⁸⁻³⁰ The Emergency Medical Dispatch protocols for caller instructions were modified for minimal interruption of CPR for bystanders. Automated defibrillators were reprogrammed for a single shock, rather than a “stacked” sequence (up to 3 shocks), delivering the highest energy level available for each shock. Manual defibrillation protocols were similarly revised. Avoiding hyperventilation was emphasized. The phase 2 intervention instructed emergency responders to control ventilation rates to 10 breaths/min and reduce intrathoracic pressures during CPR by using the impedance threshold device as an adjunct to any advanced airway used during resuscitation. During phase 2, direct observation by members of the Office of Medical Affairs, as well as feedback from providers, made it clear that high-quality, minimally interrupted compressions could be best accomplished on the scene, rather than during movement/transport of the patient. At the paramedic’s discretion, patients were transported at any point during the resuscitation. Consequently, an existing policy about field

termination and the importance of “working resuscitations where they were found” was emphasized during educational sessions (all protocols available at <http://www.wakegov.com/ems>). Policies were created about disposition of patients who died in the field, and grief support education was provided for EMS personnel. The final intervention in phase 3 introduced out-of-hospital therapeutic hypothermia for eligible patients with return of spontaneous circulation, regardless of initial rhythm, using an adaptation of the hypothermia protocol by Kim et al.³¹ Patients were cooled in the field by application of chemical cold packs and administration of 2°C to 4°C (35.6°F to 91.4°F) intravenous saline solution.³¹ All patients undergoing postresuscitation hypothermia were transported to one of the 2 percutaneous coronary intervention hospitals for continued hypothermia therapy. Continuation of hypothermia was at the discretion of the emergency physician. The target temperature was maintained at 33°C with an intravascular technique for 24 hours. (Complete protocol at <http://www.wakeems.com/ICE/ihv11.13.pdf>.)

Methods of Measurement

The primary outcome was survival to hospital discharge. Secondary outcomes included pulse on emergency department (ED) arrival, survival to hospital admission, and neurologic status at discharge from either the initial hospital or hospital-associated rehabilitation facility. Consistent with previous hypothermia studies, good neurologic outcome was defined as a Cerebral Performance Category score of 1 or 2 on a 5-point scale, in which a score of 1 indicates good cerebral performance and 2 indicates moderate cerebral disability, including sufficient cerebral function for independent activities of daily life.^{32,33}

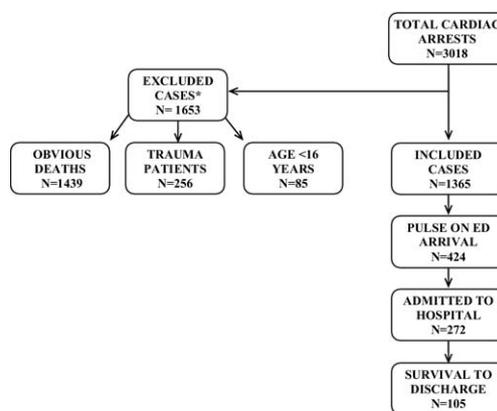
Study data were captured from the EMS System’s Utstein-style cardiac arrest quality assurance database and included initial rhythm, residential (private home, nursing facility, and assisting living facility) versus nonresidential location of arrest, bystander CPR, witnessed arrest, first-responder defibrillation, EMS interventions, response interval data, on-scene interval data, patient status after EMS interventions, hospital destination, and all study endpoints except for neurologic status at discharge.³⁴ In this system, patient data are manually entered into an electronic patient care reporting system by EMS providers immediately after the patient encounter. Electronic dispatch intervals were obtained from a separate database maintained by the 911 centers. Select data elements are then exported from the electronic patient care report to the cardiac arrest database. Additional data points and survival outcomes are manually abstracted from the patient care report and hospital records to the cardiac arrest database by trained EMS quality assurance personnel performing postevent review. All patients for whom the procedure of “CPR” or “defibrillation” was listed as an intervention, as well as those with a clinical impression of “cardiac arrest” per the ALS provider, are included in the database regardless of cause of their arrest. Throughout all phases, all ALS providers used the same electronic patient care report system, and the procedure for data

abstraction into the cardiac arrest database remained unchanged. Multiple ALS unit responses were associated by a single response number and thus did not require manual reconciliation. These data collection procedures were unchanged through the phases, and EMS providers received no change in direction or feedback about their documentation, from which database elements were abstracted. Four physicians, 2 from each of the 24-hour percutaneous coronary intervention receiving hospitals, provided an independent and blinded assessment of surviving patients' Cerebral Performance Category score at discharge, based on a review of the discharge summaries, neurology consultations, or intake history and physical examinations from rehabilitation facilities. When evaluators disagreed about neurologic scores, consensus was obtained through moderated discussion.

Primary Data Analysis

The association between survival rate and implementation of all recommendations in the final phase was evaluated with χ^2 analysis. All analyses were performed on an intention-to-treat basis, with each subsequent phase incorporating the interventions from previous phases. Ninety-five percent confidence intervals (CIs) were calculated for the absolute difference in survival rates between phases. The number needed to treat to generate good neurologic outcome (Cerebral Performance Category score 1 or 2) and the number needed to harm to produce a poor neurologic outcome (Cerebral Performance Category score 3 or 4) were determined for the cumulative therapies of the full implementation phase versus the baseline phase.

Differences between phases for other data were analyzed with the Wilcoxon rank-sum test, the χ^2 test, Fisher's exact test, or Student's *t* test, as appropriate. Adjusted odds ratios (ORs) for survival to hospital discharge comparing each phase to the baseline phase were determined by multivariate logistic regression analysis, controlling for possible confounding variables: age, sex, race/ethnicity, arrest location, bystander-witnessed arrest, bystander- or first-responder-initiated CPR, initial cardiac rhythm, and response interval from 911 call to arrival of the first defibrillator on scene. These variables were carefully selected for modeling from those considered to be both clinically and statistically related to survival.^{7,35} EMS-witnessed cases were automatically excluded from the logistic regression because meaningful values for response intervals and bystander-initiated CPR were missing. Hospital characteristics or interventions (eg, percutaneous coronary intervention-capable hospital) were not offered to the model because we would lose a significant number of cases for modeling owing to missing values for those cases that were terminated in the field. We evaluated for multicollinearity using collinearity diagnostics and the variance inflation factor. The variance inflation was low enough for each of the variables that we did not pursue interaction terms or other model diagnostics any further. Hosmer and Lemeshow goodness-of-fit and receiver operating characteristic curve statistics were assessed.



*Subgroups of excluded cases add up to greater than 1653 as some cases had two or more reasons for exclusion. ED denotes Emergency Department.

Figure 1. Overall out-of-hospital cardiac arrest patient flow for all study phases.

The κ coefficient was calculated to measure the interobserver agreement for the physician evaluations of survivors' Cerebral Performance Category scores before moderated consensus. A reliable estimate was defined a priori as κ greater than 0.6.³⁶

RESULTS

Overall, EMS responded to 3,018 cardiac arrest calls. Figure 1 displays the disposition of patients throughout the study. The proportion of patients meeting criteria for obvious death remained unchanged throughout the study phases. A total of 1,365 consecutive patients received resuscitative care and were included: 425 patients in the baseline phase (January 1, 2004, to April 14, 2005), 369 in phase 1 (April 15, 2005, to April 17, 2006), 161 in phase 2 (April 18, 2006, to October 4, 2006), and 410 in phase 3, the full implementation (October 5, 2006, to October 4, 2007).

Across study phases, patients had similar demographic, clinical, and EMS characteristics for most variables. However, compared with the baseline phase, successive phases had shorter median EMS response intervals, increased rates of initial CPR by firefighter first responders, a greater proportion of field-terminated resuscitation, and longer on-scene resuscitation intervals (Table 1).

All primary and secondary survival outcomes showed statistically significant improvement between full implementation and baseline phases (Table 2). Survival to hospital discharge for all rhythm groups combined improved by 7.3% (95% CI 3.7% to 10.9%; $P=.0002$). This improved hospital discharge rate in the full implementation phase represents an additional 3 lives saved per 100,000 population. The number needed to treat for all rhythms in full implementation versus baseline is 20 and the number needed to harm is 50 patients. When the same calculation is performed on the subset of patients experiencing initial rhythm of ventricular fibrillation or ventricular tachycardia, the number needed to treat is 4, whereas the number needed to harm remains unchanged.

Table 1. Patient, EMS, and clinical characteristics of 1,365 included patients with out-of-hospital cardiac arrest for whom resuscitation was attempted.

Characteristics	Baseline (N=425)	Phase 1 (N=369)	Phase 2 (N=161)	Phase 3 (N=410)
Mean age, y (SD)	64.2 (17.3)	65.0 (16.0)	65.6 (15.6)	64.2 (16.7)
Male sex	259 (60.9)	234 (63.4)	96 (59.6)	239 (58.3)
Race/ethnicity	n=400	n=359	n=155	n=398
Black	127 (31.8)	116 (32.3)	52 (33.6)	132 (33.2)
White	257 (64.3)	226 (63.0)	100 (64.5)	248 (62.3)
Hispanic	5 (1.3)	6 (1.7)	1 (0.7)	6 (1.5)
Other	11 (2.8)	11 (3.1)	2 (1.3)	12 (3.0)
Location of arrest: residence	376 (88.5)	309 (83.7)	136 (84.5)	357 (87.1)
Witnessed arrest	n=373	n=333	n=144	n=388
Bystander-witnessed arrest	154 (41.3)	134 (40.2)	61 (42.4)	136 (35.1)
EMS-witnessed arrest	51 (13.7)	50 (15.0)	12 (8.3)	47 (12.1)
Initial cardiac rhythm	n=424	n=368	n=161	n=403
Asystole	200 (47.2)	178 (48.4)	81 (50.3)	199 (49.4)
Pulseless electrical activity	100 (23.6)	89 (24.2)	38 (23.6)	107 (26.6)
Ventricular fibrillation or tachycardia	124 (29.3)	101 (27.5)	42 (26.1)	97 (24.1)
Initial CPR	n=418	n=365	n=161	n=402
Bystander	162 (38.8)	117 (32.1)	63 (39.1)	142 (35.3)
First responder (firefighter)	143 (34.2)	165 (45.2)	77 (47.8)	192 (47.8)
Ambulance	113 (27.0)	83 (22.7)	21 (13.0)	68 (16.9)
First responder defibrillated	89 (20.9)	52 (14.1)	3 (1.9)	37 (9.0)
EMS response intervals	n=398	n=357	n=160	n=403
Median (IQR) defibrillator to scene, min	6.1 (4.9–7.6)	5.6 (4.2–6.9)	5.4 (4.1–6.9)	5.4 (4.3–6.9)
Defibrillator to scene in ≤8 min	315 (79.2)	310 (86.8)	137 (85.6)	356 (88.3)
Defibrillator to scene in ≤4 min	42 (10.6)	70 (19.6)	39 (24.4)	73 (18.1)
On-scene intervals	n=361	n=271	n=99	n=256
Median (IQR) EMS on scene, min	23.0 (18.0–28.0)	25.0 (20.0–32.0)	30.0 (23.0–37.0)	33.5 (25.0–43.0)
Airway	n=414	n=364	n=161	n=404
Bag-valve-mask only	32 (7.7)	56 (15.4)	18 (11.2)	31 (7.7)
Endotracheal intubation	355 (85.8)	289 (79.4)	129 (80.1)	332 (82.2)
Laryngeal mask airway	20 (4.8)	15 (4.1)	11 (6.8)	29 (7.2)
Cricothyrotomy	1 (0.2)	0 (0)	2 (1.2)	1 (0.2)
Termination of resuscitation in the field	48 (11.3)	95 (25.8)	61 (37.9)	167 (40.7)
Field-induced therapeutic hypothermia	N/A	N/A	N/A	87 (21.8)
Receiving hospital*	n=374	n=274	n=100	n=239
PCI-capable hospital	252 (67.4)	183 (66.8)	68 (68.0)	206 (86.2)

IQR, Interquartile range; N/A, not applicable; PCI, percutaneous cardiac intervention.

All data are presented as No. (%) unless otherwise noted.

*Receiving hospital sample includes only those resuscitation patients who were transported to a hospital.

Table 2. Survival outcomes from each of the study phases for all 1,365 included out-of-hospital cardiac arrest patients for whom resuscitation was attempted and neurologic outcomes for those patients who survived to hospital discharge.

Characteristics	Baseline (N=425)	Phase 1 (N=369)	Phase 2 (N=161)	Phase 3 (N=410)	Absolute Increase* % (95% CI)
Survival outcome					
Any ROSC	105 (24.7)	148 (40.1)	66 (41.0)	178 (43.4)	18.7 (12.4 to 25.0)
Pulse on ED arrival	98 (23.1)	136 (36.9)	52 (32.3)	138 (33.7)	10.6 (4.5 to 16.7)
Admitted to hospital	55 (12.9)	65 (17.6)	31 (19.3)	121 (29.5)	16.6 (11.2 to 22.0)
Discharged from hospital	18 (4.2)	27 (7.3)	13 (8.1)	47 (11.5)	7.3 (3.7 to 10.9)
Survivors' CPC score	n=14	n=25	n=12	n=47	
1 and 2	11 (78.6)	19 (76.0)	10 (83.3)	36 (76.6)	−2.0 (−26.6 to 22.7)
3 and 4	3 (21.4)	6 (24.0)	2 (16.7)	11 (23.4)	2.0 (−22.7 to 26.6)

ROSC, Return of spontaneous circulation; CPC, cerebral performance category.

All data are presented as No. (%) survivors unless otherwise noted.

*Absolute increase and 95% CI for comparison between baseline and phase 3 (full implementation). CPC 1 and 2 denote "good" and "moderate" cerebral performance; 3 and 4 denote "poor" and "vegetative" cerebral performance; 5 denotes "brain death" and thus is not represented.

Table 3. Survival of clinically important subgroups of out-of-hospital cardiac arrest through all study phases.

Characteristics	Baseline (N=425)	Phase 1 (N=369)	Phase 2 (N=161)	Phase 3 (N=410)	Absolute Increase* % (95% CI)
Witnessed arrest					
Bystander witnessed	n=154 8 (5.2)	n=134 14 (10.4)	n=61 8 (13.1)	n=136 31 (22.8)	17.6 (9.7 to 25.5)
EMS witnessed	n=51 6 (11.8)	n=50 6 (12.0)	n=12 1 (8.3)	n=47 10 (21.3)	9.5 (-5.2 to 24.2)
Initial CPR					
Bystander	n=162 8 (4.9)	n=117 13 (11.1)	n=63 6 (9.5)	n=142 21 (14.8)	9.9 (3.2 to 16.6)
First responder (firefighter)	n=143 2 (1.4)	n=165 6 (3.6)	n=77 5 (6.5)	n=192 14 (7.3)	5.9 (1.7 to 10.1)
EMS response intervals					
Defib to scene in >4 min	n=356 16 (4.5)	n=287 16 (5.6)	n=121 9 (7.4)	n=330 35 (10.6)	6.1 (2.1 to 10.1)
Defib to scene in ≤4 min	n=42 1 (2.4)	n=70 9 (12.9)	n=39 4 (10.3)	n=73 12 (16.4)	11.6 (0.9 to 22.3)
Initial cardiac rhythm					
Asystole	n=200 3 (1.5)	n=178 2 (1.1)	n=81 1 (1.2)	n=199 4 (2.0)	0.5 (-2.1 to 3.1)
PEA	n=100 1 (1.0)	n=89 3 (3.4)	n=38 0 (0)	n=107 8 (7.5)	5.5 (-0.2 to 11.2)
VF or VT	n=124 14 (11.3)	n=101 22 (21.8)	n=42 12 (28.6)	n=97 35 (36.1)	24.8 (13.7 to 35.9)
Witnessed VF					
All-witnessed VF	n=80 11 (13.8)	n=71 17 (23.9)	n=26 9 (34.6)	n=76 31 (40.8)	27.0 (13.6 to 40.4)
Bystander-witnessed VF	n=61 5 (8.2)	n=56 12 (21.4)	n=24 8 (33.3)	n=66 23 (34.8)	26.6 (13.2 to 40.0)
EMS-witnessed VF	n=19 6 (31.6)	n=15 5 (33.3)	n=2 1 (50.0)	n=10 8 (80.0)	48.4 (16.0 to 80.8)
Airway procedures					
Bag-valve-mask only	n=32 4 (12.5)	n=56 13 (23.2)	n=18 7 (38.9)	n=31 10 (32.3)	19.8 (-0.3 to 39.9)
Tracheal intubation	n=355 7 (2.0)	n=289 11 (3.8)	n=129 5 (3.9)	n=332 27 (8.1)	6.1 (2.8 to 9.4)
Therapeutic hypothermia					
Field induction	N/A N/A	N/A N/A	N/A N/A	n=87 13 (14.9)	N/A N/A
Receiving hospital					
PCI-capable hospital	n=252 11 (4.4)	n=183 20 (10.9)	n=68 9 (13.2)	n=206 41 (19.9)	N/A 15.5 (9.5 to 21.5)

Defib, Defibrillator; PEA, pulseless electrical activity; VF, ventricular fibrillation; VT, ventricular tachycardia.

All data are presented as No. (%) survivors unless otherwise noted.

*Absolute increase and 95% CI for comparison between baseline and phase 3 (full implementation).

Survival rates also improved for several clinically important subgroups, including bystander-witnessed arrest, initial CPR by bystander, initial CPR by first responders, and witnessed ventricular fibrillation/ventricular tachycardia (Table 3).

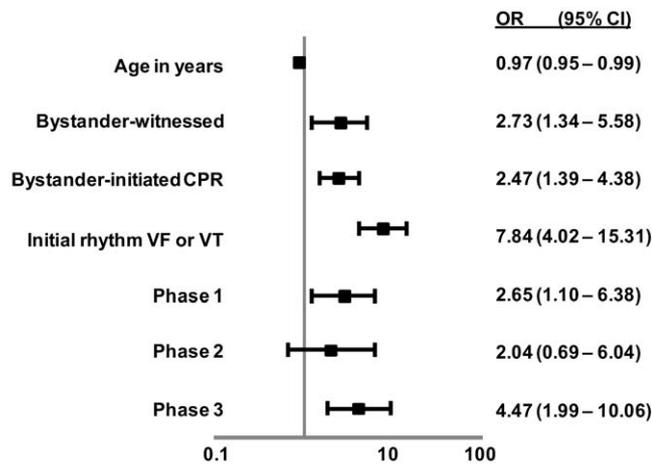
After controlling for potential confounders, logistic regression analysis found the OR for survival for the full implementation phase versus baseline was 4.5 (95% CI 2.0 to 10.1) (Figure 2). In addition, the following ORs were significant: patient age, bystander-witnessed arrest, bystander-initiated CPR, and initial cardiac rhythm of ventricular fibrillation/ventricular tachycardia.

Good or moderate Cerebral Performance Category scores (ie, 1 or 2, respectively) for survivors at discharge were

achieved by about three quarters of survivors, regardless of phase (Table 2). For all survivors, the weighted κ between the 2 physician reviewers for determining Cerebral Performance Category score was 0.69 (95% CI 0.56 to 0.83).

LIMITATIONS

Although randomized controlled trials best identify causal associations between individual interventions and outcome, our community did not approach the implementation of these treatments with clinical equipoise; rather, we were implementing treatments supported by existing evidence and believed that our EMS providers and other health care providers



*EMS-witnessed cases were excluded as they are considered to be a distinct population of out-of-hospital cardiac arrest.⁴⁰ Due to listwise reduction of cases with missing data, 998 (82.8%) of 1205 eligible cases were included in this multivariate logistic regression analysis. The goodness of fit for the model was 3.1 with 8 degrees of freedom ($P=0.93$). The area under the receiver-operating-characteristic curve was 0.87. CI denotes confidence interval. CPR denotes cardiopulmonary resuscitation. OR denotes odds ratio.

Figure 2. ORs for out-of-hospital cardiac arrest survival to hospital discharge associated with selected factors and study phases.*

would be concerned about withholding treatments from patients.³⁷ Our system adopted a progressive, evidence-based approach to protocol change, with preimplementation educational sessions for each protocol update. This dynamic approach makes the population-based before-after-type study design most appropriate for our system. Our ongoing quality improvement program includes contemporaneous data collection of all attempted resuscitations into a cardiac arrest database, thus maintaining our inclusion/exclusion criteria over time, ensuring data accuracy, and minimizing selection bias.

Our study had several other potential limitations. As discussed above, we used historical controls in this before-after study design. During the 4 years, it is possible there were changes in care not accounted for in our data. We used the same electronic call report, database, and individuals to abstract data during the entire period and made every attempt to account for as many variables as our data would allow. Second, our study may have contributed to a Hawthorne-like effect (ie, increased survival rates may have been attributed to improved provider performance because of increased attention to resuscitation care). In addition, the number and geographic distribution of automated external defibrillators (AEDs) and manufacturer variation in the release of 2005 AHA guideline-compliant software upgrades also precluded the establishment of a uniform date for implementing programming changes to AEDs in our system, which resulted in a gradual transition from stacked AED shocks to single AED shocks during several months in phase 1. Additionally, protocol revisions including implementation of new interventions are typically made annually in our system, which limited the number of patients in each study phase to the number treated by EMS in that period, although only 6 months into phase 2, the hospitals announced their readiness to

participate in a therapeutic hypothermia protocol, prompting a midyear protocol update to begin hypothermia in our community (phase 3).

The uniform availability of introduced therapies necessitated an intention-to-treat analysis. This programmatic approach limited the ability to demonstrate the benefit directly attributable to any individual treatment modality. Nonetheless, a post hoc power calculation determined that a sample size of 425 in the baseline phase and 410 in the full implementation phase had greater than 80% power to detect a 5% absolute difference in survival from baseline to full implementation, assuming a 2-sided $\alpha=.05$.

DISCUSSION

This is a report of a community-wide health system's implementation of the AHA 2005 Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care through all components of the Chain of Survival. Sequentially and additively, our EMS system implemented the updated protocols (minimally interrupted chest compressions, strict avoidance of hyperventilation, and postresuscitation hypothermia therapy to improve neurologic status of survivors). This approach more than doubled the overall survival to hospital discharge rate for all attempted resuscitations while maintaining the proportion of survivors who experienced good neurologic outcome. Thus, not only were more lives saved but also more patients survived with good neurologic outcome. Our results translate to an additional 25 lives saved annually in this study community, or 3 additional lives per 100,000. Although there were statistically significant adjusted ORs for survival associated with phase 1 and phase 3 (full implementation) compared with the baseline phase, our study design does not allow for evaluation of the specific contributions of each intervention. The individual protocol changes may have independently improved outcomes; however, we believe that the additive effect of the new protocols contributed to the dramatic increase in survival from baseline.

The 2005 AHA guidelines recommendations were developed during a 3-year period by an international panel of nearly 300 experts.³⁸ Many guideline changes were made by consensus after a comprehensive evaluation of laboratory, clinical, and educational data. The most important updates to the 2005 guidelines were changes in the compression to ventilation ratio, compressions first versus early defibrillation for unwitnessed ventricular fibrillation/ventricular tachycardia, 1-shock versus 3-shock sequence for attempted defibrillation, minimal interruptions in chest compressions through de-emphasis of ventilations, and emphasis on postresuscitation care, including induced hypothermia. Simply stated, the guidelines encouraged rescuers to "push hard, push fast, allow complete chest recoil between compressions, and minimize interruptions in compressions."^{4,10,11}

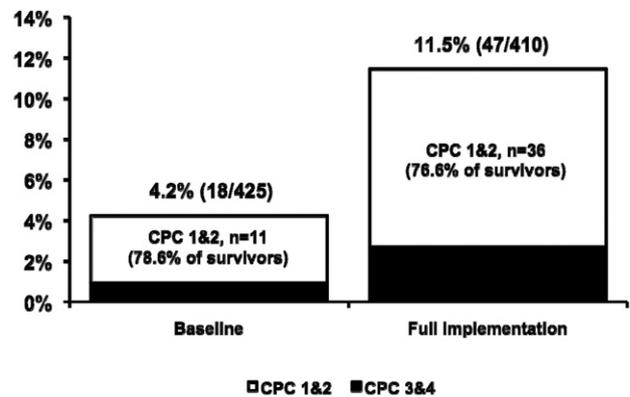
Before implementation of 2005 guidelines, we already established strengths in the initial links of our community's chain of survival, with a 36% bystander CPR rate, dispatch-

assisted CPR program, and rapid EMS response that relied on firefighter first responders trained in automated external defibrillation. Our EMS system had mandatory monthly continuing education sessions; continuous quality improvement for cardiac arrest calls, including regular on-scene medical oversight; and a minimum 5-person response team to allow for rotation of compression providers.

As the study progressed, EMS characteristics revealed a shorter defibrillation response interval, which has previously been shown to have a significant and independent relationship with survival.³⁵ We did not establish this same independent relationship in our data and found a significant univariate association with survival only when the response interval was less than or equal to 4 minutes. This outcome may be due to high rates of bystander- and first-responder-initiated CPR, as well as the increased emphasis on quality CPR in our community. Others have observed that effective compressions improve the morphology of the ventricular fibrillation waveform, increasing the probability of successful defibrillation even if defibrillation is delayed.¹³

The decrease in the proportion of patients who received defibrillations from the fire department AEDs from baseline to phase 3 is noteworthy. The proportion of patients in ventricular fibrillation remained constant throughout the phases, and there were no specific instructions for firefighter first responders to increase or decrease the use of their AEDs. As part of the emphasis on compressions, we did review the data from Cobb et al about the positive effect of compressions prior to defibrillation with all firefighters.^{12,23,24,39-44} Thus, we hypothesize that ALS arrived during these preshock compressions and the ALS monitor was used to deliver the defibrillations. Because of the inability to electronically gather data from the fire department AEDs throughout the study and from the ALS monitors for portions of the study, we cannot confirm this hypothesis.

The increasing proportion of resuscitations terminated in the field between the initial and final phases of the trial deserves particular attention. From an outcomes perspective, the proportion of survivors and the proportion of survivors with good neurologic outcome were calculated according to all attempted resuscitations in each of the phases, regardless of whether the patient was transported or died in the field. This change in practice did not alter the number of moribund patients included in the analysis; rather, increased field termination of resuscitation was the result of providing resuscitation to patients longer in the field to minimize pauses in compressions because of patient movement and transport and thus to optimize the quality of CPR provided. Our field observations indicate that affording EMS providers greater time on scene allows them to perform continuous compressions and reduces hand-off time, particularly in the absence of mechanical compressions devices. This increased time on scene and the corresponding increase in field terminations (as more patients were provided resuscitation to



*Neurologic status is represented by Cerebral Performance Category (CPC); 1&2 denote "good" and "moderate" cerebral performance; 3&4 denote "poor" and "vegetative" cerebral performance; 5 denotes "brain death" and thus is not represented in this survivor to hospital discharge bar chart. ** Survivors in baseline phase where CPC score available = 14.

Figure 3. Overall survival to hospital discharge and neurologic status* of survivors of out-of-hospital cardiac arrest between baseline (N=425) and full implementation (N=410) of 2005 AHA guidelines (phase 3).

the point of futility) were simply a natural by-product of the focus on quality compressions.

Unlike traditional EMS treatments that can be standardized by a focused protocol change in the field, implementing therapeutic hypothermia required a complex interdisciplinary approach involving key personnel from EMS and the departments of emergency medicine, cardiology, intensive care, and neurology. Before implementing the induced hypothermia protocol, our health care systems lacked a standardized in-hospital protocol to treat postarrest patients. During the full implementation phase, the 2 percutaneous coronary intervention hospitals in our community adopted protocols that included many aspects of postresuscitation care, including initiating and continuing induced hypothermia for patients with out-of-hospital cardiac arrest.

We were concerned that simply increasing the proportion of patients transported directly to high-volume, percutaneous coronary intervention–capable facilities may have contributed to our improved survival rates. According to baseline phase and phase 3 comparisons, the proportion of patients surviving to discharge from the percutaneous coronary intervention hospitals increased significantly, suggesting one or more interventions other than simple transport to the percutaneous coronary intervention hospital contributed to the results.

There was concern from some health care providers that improved survival rates would be coupled with a disproportionate number of survivors with devastating neurologic outcomes. However, the proportion of survivors with good neurologic outcome remained constant through the study phases (Figure 3). Thus, in absolute terms, a greater number of patients survived to discharge with good neurologic outcome as the phases progressed.

The relative roles of EMS, standardization of care, use of hypothermia, and the selective routing to destination hospitals

as they relate to the improved survival rates are unclear and require further evaluation in additional trials, such as those from the ongoing Resuscitation Outcomes Consortium.⁴⁵

This study population had improved survival rates after the stepwise introduction of the 2005 AHA guidelines, including EMS-initiated therapeutic hypothermia in conjunction with a community-wide approach involving care providers from 911 dispatch through emergency and intensive care departments. EMS systems should work in collaboration with their receiving hospitals to develop a multidisciplinary approach to improve their chain of survival for out-of-hospital cardiac arrest. Further study of the implementation of the 2005 AHA guidelines is warranted to better elucidate the relative effects of individual interventions on survival outcomes.

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REFERENCES

- Eisenberg MS, Horwood BT, Commins RO, et al. Cardiac arrest and resuscitation: a tale of 29 cities. *Ann Emerg Med.* 1990;19:179-186.
- Nichol G, Thomas E, Callaway CW, et al. Regional variation in out-of-hospital cardiac arrest incidence and outcome. *JAMA.* 2008;300:1423-1431.
- Cummins RO, Ornato JP, Thies WH, et al. Improving survival from sudden cardiac arrest: the "chain of survival" concept. A statement for health professionals from the Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee, American Heart Association. *Circulation.* 1991;83:1832-1847.
- American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiac care. *Circulation.* 2005;112(24 suppl):1-88.
- Stiell IG, Wells GA, Field B, et al. Advanced cardiac life support in out-of-hospital cardiac arrest. *N Engl J Med.* 2004;351:647-656.
- Peberdy MA, Ornato JP. Progress in resuscitation: an evolution, not a revolution. *JAMA.* 2008;299:1188-1190.
- Stiell IG, Wells GA, Field B, et al. Improved out-of-hospital cardiac arrest survival through the inexpensive optimization of an existing defibrillation program: OPALS study phase II. Ontario Prehospital Advanced Life Support. *JAMA.* 1999;281:1175-1181.
- Yu T, Weil MH, Tang W, et al. Adverse outcomes of interrupted precordial compression during automated defibrillation. *Circulation.* 2002;106:368-372.
- Aufderheide TP, Lurie KG. Death by hyperventilation: a common and life-threatening problem during cardiopulmonary resuscitation. *Crit Care Med.* 2004;32(9 suppl):S345-351.
- Aufderheide TP, Pirralo RG, Yannopoulos D, et al. Incomplete chest wall decompression: a clinical evaluation of CPR performance by trained laypersons and an assessment of alternative manual chest compression-decompression techniques. *Resuscitation.* 2006;71:341-351.
- Aufderheide TP, Sigurdsson G, Pirralo RG, et al. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. *Circulation.* 2004;109:1960-1965.
- Bernard S. Therapeutic hypothermia after cardiac arrest: now a standard of care. *Crit Care Med.* 2006;34:923-924.
- Eftestol T, Sunde K, Steen PA. Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest. *Circulation.* 2002;105:2270-2273.
- Ewy GA. Cardiac arrest—guideline changes urgently needed. *Lancet.* 2007;369:882-884.
- Fries M, Tang W. How does interruption of cardiopulmonary resuscitation affect survival from cardiac arrest? *Curr Opin Crit Care.* 2005;11:200-203.
- Pepe PE, Roppolo LP, Fowler RL. The detrimental effects of ventilation during low-blood-flow states. *Curr Opin Crit Care.* 2005;11:212-218.
- Valenzuela TD, Kern KB, Clark LL, et al. Interruptions of chest compressions during emergency medical systems resuscitation. *Circulation.* 2005;112:1259-1265.
- Casner M, Andersen D, Isaacs SM. The impact of a new CPR assist device on rate of return of spontaneous circulation in out-of-hospital cardiac arrest. *Prehosp Emerg Care.* 2005;9:61-67.

19. Hallstrom A, Rea TD, Sayre MR, et al. Manual chest compression vs use of an automated chest compression device during resuscitation following out-of-hospital cardiac arrest: a randomized trial. *JAMA*. 2006;295:2620-2628.
20. Ong ME, Ornato JP, Edwards DP, et al. Use of an automated, load-distributing band chest compression device for out-of-hospital cardiac arrest resuscitation. *JAMA*. 2006;295:2629-2637.
21. Kellum MJ, Kennedy KW, Ewy GA. Cardiocerebral resuscitation improves survival of patients with out-of-hospital cardiac arrest. *Am J Med*. 2006;119:335-340.
22. SOS-KANTO Study Group. Cardiopulmonary resuscitation by bystanders with chest compression only (SOS-KANTO): an observational study. *Lancet*. 2007;369:920-926.
23. Bernard SA, Gray TW, Buist MD, et al. Treatment of comatose survivors of out-of-hospital cardiac arrest with induced hypothermia. *N Engl J Med*. 2002;346:557-563.
24. Hypothermia After Cardiac Arrest Study Group. Mild therapeutic hypothermia to improve the neurologic outcome after cardiac arrest. *N Engl J Med*. 2002;346:549-556.
25. Yannopoulos D, Aufderheide TP, Gabrielli A, et al. Clinical and hemodynamic comparison of 15:2 and 30:2 compression-to-ventilation ratios for cardiopulmonary resuscitation. *Crit Care Med*. 2006;34:1444-1449.
26. Thayne RC, Thomas DC, Neville JD, et al. Use of an impedance threshold device improves short-term outcomes following out-of-hospital cardiac arrest. *Resuscitation*. 2005;67:103-108.
27. Cummins RO, Hazinski MF. The most important changes in the international ECC and CPR guidelines 2000. *Circulation*. 2000;102(8 suppl):I371-376.
28. Bobrow BJ, Clark LL, Ewy GA, et al. Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. *JAMA*. 2008;299:1158-1165.
29. Ewy GA. Continuous-chest-compression cardiopulmonary resuscitation for cardiac arrest. *Circulation*. 2007;116:2894-2896.
30. Sayre MR, Berg RA, Cave DM, et al. Hands-only (compression-only) cardiopulmonary resuscitation: a call to action for bystander response to adults who experience out-of-hospital sudden cardiac arrest: a science advisory for the public from the American Heart Association Emergency Cardiovascular Care Committee. *Circulation*. 2008;117:2162-2167.
31. Kim F, Olsufka M, Longstreth WT Jr, et al. Pilot randomized clinical trial of prehospital induction of mild hypothermia in out-of-hospital cardiac arrest patients with a rapid infusion of 4 degrees C normal saline. *Circulation*. 2007;115:3064-3070.
32. Hypothermia After Cardiac Arrest Study Group. A randomized clinical trial of calcium entry blocker administration to comatose survivors of cardiac arrest: design, methods, and patient characteristics. *Control Clin Trials*. 1991;12:525-545.
33. Booth CM, Boone RH, Tomlinson G, et al. Is this patient dead, vegetative, or severely neurologically impaired? assessing outcome for comatose survivors of cardiac arrest. *JAMA*. 2004;291:870-879.
34. Eisenberg MS, Cummins RO, Damon S, et al. Survival rates from out-of-hospital cardiac arrest: recommendations for uniform definitions and data to report. *Ann Emerg Med*. 1990;19:1249-1259.
35. De Maio VJ, Stiell IG, Wells GA, et al. Optimal defibrillation response intervals for maximum out-of-hospital cardiac arrest survival rates. *Ann Emerg Med*. 2003;42:242-250.
36. Altman G. *Practical Studies for Medical Research*. London, England: Chapman and Hall; 1991.
37. Stiell IG, Wells GA, Spaite DW, et al. The Ontario Prehospital Advanced Life Support (OPALS) Study: rationale and methodology for cardiac arrest patients. *Ann Emerg Med*. 1998;32:180-190.
38. Hazinski MF, Nadkarni VM, Hickey RW, et al. Major changes in the 2005 AHA guidelines for CPR and ECC: reaching the tipping point for change. *Circulation*. 2005;112(24 suppl):IV206-211.
39. Cobb LA, Fahrenbruch CE, Walsh TR, et al. Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation. *JAMA*. 1999;281:1182-1188.
40. Bernard S. Hypothermia after cardiac arrest: how to cool and for how long? *Crit Care Med*. 2004;32:897-899.
41. Bernard SA, Rosalio A. Therapeutic hypothermia induced during cardiopulmonary resuscitation using large-volume, ice-cold intravenous fluid. *Resuscitation*. 2008;76:311-313.
42. Holzer M, Bernard SA, Hachimi-Idrissi S, et al. Hypothermia for neuroprotection after cardiac arrest: systematic review and individual patient data meta-analysis. *Crit Care Med*. 2005;33:414-418.
43. Kuboyama K, Safar P, Radovsky A, et al. Delay in cooling negates the beneficial effect of mild resuscitative cerebral hypothermia after cardiac arrest in dogs: a prospective, randomized study. *Crit Care Med*. 1993;21:1348-1358.
44. Madl C, Holzer M. Brain function after resuscitation from cardiac arrest. *Curr Opin Crit Care*. 2004;10:213-217.
45. Morrison LJ, Nichol G, Rea TD, et al. Rationale, development and implementation of the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest. *Resuscitation*. 2008;78:161-169.

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