Implementing the 2005 American Heart Association Guidelines improves outcomes after out-of-hospital cardiac arrest

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OBJECTIVE The purpose of the study was to determine whether applying highly recommended changes in the 2005 American Heart Association (AHA) Guidelines would improve outcomes after out-of-hospital cardiac arrest.

BACKGROUND In 2005, AHA recommended multiple ways to improve circulation during cardiopulmonary resuscitation (CPR).

METHODS Conglomerate quality assurance data were analyzed during prospective implementation of the 2005 AHA Guidelines in five emergency medical services (EMS) systems. All EMS personnel were trained in the key new aspects of the 2005 AHA Guidelines, including use of an impedance threshold device. The primary outcome was survival to hospital discharge. Secondary outcomes were return of spontaneous circulation (ROSC), survival by initial cardiac arrest rhythm, and the cerebral performance category (CPC) score at hospital discharge.

RESULTS There were 1,605 patients in the intervention group and 1,641 patients in the control group. Demographics, the rate of bystander CPR, and time from the 911 call for help to arrival of EMS personnel were similar between groups. Survival to hospital discharge was 10.1% in the control group versus 13.1% in the intervention group ($P = .007$). For patients with a presenting rhythm of ventricular fibrillation/ventricular tachycardia, survival to discharge was 20% in controls versus 32.3% in the intervention group ($P < .001$). Survival to discharge with a CPC classification of 1 or 2 was 33.3% (10/30) in the control versus 59.6% (31/52) in the intervention group ($P = .038$).

CONCLUSIONS Compared with controls, patients with out-of-hospital cardiac arrest treated with a renewed emphasis on improved circulation during CPR had significantly higher neurologically intact hospital discharge rates.

KEYWORDS Cardiac arrest; Sudden death; Impedance threshold device; CPR; Ventricular fibrillation

ABBREVIATIONS AHA = American Heart Association; **ALS** = advanced life support; **BLS** = basic life support; **CI** = confidence intervals; **CPC** = cerebral performance category; **CPR** = cardiopulmonary resuscitation; **EMS** = emergency medical services; **$ETCO_2$** = end tidal carbon dioxide; **ITD** = impedance threshold device; **OR** = odds ratio; **ROSC** = return of spontaneous circulation; **VF** = ventricular fibrillation

Introduction

Maximizing outcomes after cardiac arrest depends on optimizing a sequence of interventions from collapse to hospital discharge.[1] The 2005 American Heart Association (AHA) Guidelines[2] recommended new interventions during cardiopulmonary resuscitation (CPR) to increase circulation. Using a well-defined, evidence-based ranking (classes I, IIa, IIb, III, and indeterminate),[2] these recommendations (for the purposes of this report termed "new CPR") included a compression-to-ventilation ratio of 30:2 (class IIa),[3] no greater than 10 breaths/minute delivered at 1 second/breath (class IIa),[4–6] a tidal volume of ~500 mL (class IIa),[6] chest compression depth of 1.5–2 inches (class IIa), complete chest recoil after each compression (class IIb),[7–9] minimal interruption of chest compressions (class IIa),[10,11] and use of an impedance threshold device (ITD; class IIa).[12–16] The

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Table 1 Key measures emphasized to increase circulation

2005 AHA Guidelines Recommendation	Class of Recommendation
1. Deliver effective compressions: 1.5–2 inches at 100 compressions/minute	I
2. Minimize interruptions between compressions	IIa
4. ITD	IIa
5. Compression to ventilation ratio of 30:2 for BLS and asynchronous ventilation at 10/minute for ALS	IIa
6. CPR for 2 minutes after shock for VF	IIa
7. CPR for 2 minutes before shock for VF if VF present for >4 minutes	IIb
8. Full chest wall recoil	IIb
9. 50% duty cycle for active chest compression: passive decompression	IIb
10. Rotate compressor every 2 minutes over <5 seconds	IIb
11. Ventilate with ~500 mL tidal volume/positive pressure breath	IIb
12. Maintain a two-handed face mask seal	Recommended without a specific class

ITD has been shown to increase circulation during CPR by (1) augmenting the refilling of the heart during the chest wall recoil phase and (2) lowering intracranial pressures.[1] Each of these new recommendations by itself has been shown to result in improved circulation during CPR.[2–16] Together, these changes result in a 100%–150% increase in circulation, as determined by changes in carotid artery blood flow and end tidal carbon dioxide (ETCO$_2$ in pigs, when compared with older strategies such as using a compression-to-ventilation ratio of 15:2.[3,16]

Despite these recommendations, little is known about the impact of this new approach on survival rates for patients with out-of-hospital cardiac arrest. The purpose of this study was to test the hypothesis that new CPR will increase hospital discharge rates and neurological outcome in patients with out-of-hospital cardiac arrest when compared with historical controls.

Methods

Anonymous, conglomerate quality assurance data were pooled from five United States emergency medical services (EMS) systems experienced in the implementation of new CPR that track outcome data from patients with out-of-hospital cardiac arrest. The five EMS systems and their respective populations (in parentheses) were Anoka County, Minnesota (330,000); a 250-square-mile region of Northwest Harris County, Texas, covered by Cypress Creek EMS (450,000); Omaha, Nebraska (340,000); Pinellas County, Florida (910,000); and Wake County, North Carolina (870,000). At the time of this evaluation, these sites had the largest cumulative experience with new CPR of any U.S. cities and/or counties. Moreover, all sites collected data on the rollout of the new CPR prospectively: historical control data were generated from the 12-month period of time immediately before full implementation of the recommended changes in the guidelines at the same sites. New CPR, as recommended in the 2005 AHA Guidelines, was deployed for 8 months in one site, 10 months in one site, and 12 months in three sites. These five EMS systems cover a combined population of ~2.9 million people. Approval for data review and analysis was obtained from the Institutional Review Board at the Medical College of Wisconsin,

All EMS systems simultaneously implemented new CPR as recommended in the 2005 AHA Guidelines (Table 1), including compression/ventilation strategies to provide more compressions/minute and continuous compressions during advanced life support (ALS). Sites stressed the importance of 1.5–2 inches of chest compression (hard and fast) and full chest wall recoil, a two-handed tight face mask seal with ITD (ResQPOD, Advanced Circulatory Systems, Roseville, MN) use at all times, a tidal volume of ~500 mL, and delivery of each breath within 1 second.[2] To accomplish full chest wall recoil, sites trained rescuers to fully compress the chest and then to lift the palm of the hand slightly but completely off the chest during the decompression phase.[7] Retraining was performed at a minimum of every 6 months. By contrast, patients were treated during the historical control period according to the 2000 AHA Guidelines that included a compression-to-ventilation ratio of 15:2 during basic life support (BLS), 10 breaths/minute once an advanced airway was secured, and three stacked shocks for patients in ventricular fibrillation (VF). The ITD was not used during the historical control period.

Entry criteria for the study included all patients with cardiac arrest in whom EMS resuscitation was attempted and met local criteria for ITD use. Exclusion criteria included cardiac arrests of presumed traumatic etiology (e.g., blunt or penetrating trauma), preexisting "do not resuscitate" orders that were found before or shortly after CPR was initiated, and obvious death. For the purposes of this study, burns and electrocutions were not considered traumatic and were included.

The age limit for the historical controls was derived using matching local criteria for ITD use. Criteria for ITD use varied. Some EMS systems applied the 2005 Guidelines and the ITD to all patients ≥12 years of age. One site used

Table 2 Average rate of bystander CPR (%)

Site	Control	Intervention
A	22*	33
B	59	55
C	42	45
D	40	41
E	29.8	32.7
Total, normalized to patient no./site	38.4	40.0

Note: P = NS for all data. Data for the control period from this site were captured from the written section of the paramedic run report and for the intervention period were captured from a checklist on the paramedic run report. Thus, the average rate of bystander CPR in the control period for this site may be underestimated.

Table 3 Average time (seconds) from 911 call for help to on-scene arrival of first EMS personnel on scene

Site	Control	Intervention
A[a]	419	474
B	689	608
C	234	258
D	288	302
E	342	340
Total, normalized to patient no./site	334	337

Note: P = NS for all data.
[a]Times from site A are from the time of dispatch to arrival of the first ALS unit, which was often but not always the first EMS unit at the scene.

a 1-year-old age limit. The ITD was used on a face mask and endotracheal tube or other advanced airway device (e.g., CombiTube) in four of five sites. One site applied the ITD only on an advanced airway. The ITD was deployed on all patients in cardiac arrest, regardless of the presumed etiology of the arrest, based on these local criteria.

Outcome data for the intervention group were collected at each site prospectively and then compared with historical controls from existing databases. All data were compiled as anonymous, conglomerate data. The quality assurance data from three of five sites included neurological status (cerebral performance category [CPC] classification) at the time of hospital discharge from all or some hospitals. Two sites did not collect neurological outcome data as part of the quality assurance process. One site (site D) acquired neurological status at hospital discharge from only one receiving hospital for all patients during both the control and intervention phases. In some sites, the window of evaluation was limited to as short as 8 months to minimize the effects of subsequent additional changes in postcardiac arrest care from complicating the interpretation of whether improved circulation during CPR improved survival and neurological outcome. Despite this, however, hospitals in two sites (sites A and E) began in-hospital therapeutic hypothermia at the end of the period of time the data were collected in the intervention group, and, as such, a total of 15 survivors from these two sites received therapeutic hypothermia in the intervention phase. The primary endpoint of the study was survival to hospital discharge rate. Secondary endpoints, determined a priori, included the rate of return of spontaneous circulation (ROSC), survival to hospital discharge based on initial cardiac arrest rhythm, and neurological status at the time of hospital discharge. Data from patients with an initial rhythm of VF and ventricular tachycardia were pooled in these analyses.

The Fisher's exact test (two-sided), odds ratios (OR), rate differences, and their associated exact confidence intervals (CI) were calculated using the statistical software package StatXact (Version 8, Cytel Software, Cambridge, MA). Because one study site provided over 900 patients to both groups, primary and secondary endpoints were also analyzed excluding that specific study site. The Cochran-Mantel-Haenszel test, the Mantel-Haenszel test, and the Breslow-Day test were also used, The Breslow-Day test was used to test the null hypothesis of a homogeneous OR across strata.

Results

There were a total of 1,605 patients in the intervention group (new CPR) and 1,641 patients in the control group. The average age and percent of all patients who were male in both groups was 64 years of age and 66%, respectively. No neonates or infants were treated or included during the study period.

The number of patients who received bystander CPR was similar between groups (Table 2). Similarly, the time between the 911 call for help and arrival of the first professional EMS personnel at the scene was similar between the historical controls and the intervention phase (Table 3).

The OR and 95% CI as well as P-values were calculated for each of the key endpoints. Using the Breslow-Day test, the Mantel-Haenszel test, and the Cochran-Mantel-Haenszel test, there was no evidence of heterogeneity of the ORs across sites. This provided the statistical basis for summarizing the results in a common OR for each endpoint. The overall ROSC rate was 30.3% in controls and 33.8% in the intervention group (P = .035; OR 1.17, CI [1.01, 1.36]; Table 4). There was a nearly 30% relative increase in survival rate to hospital discharge, from 10.1% in controls to 13.1% in the intervention group (Table 5). These differences were statistically significant (P = .007; OR 1.34, CI [1.08, 1.68]). The effect of the new interventions was most pronounced in patients presenting with an initial cardiac

Table 4 ROSC

Site	Control	Intervention	P[a]	OR (95% CI)
A	37.1 (36/97)	38.5 (35/91)	.881	1.06 (0.56, 1.99)
B	40.8 (53/130)	46.0 (46/100)	.502	1.24 (0.71, 2.17)
C	23.2 (35/151)	36.9 (58/157)	.009	1.94 (1.15, 3.31)
D	26.4 (238/901)	30.9 (287/929)	.039	1.25 (1.01, 1.53)
E	37.6 (136/362)	35.7 (117/328)	.635	0.92 (0.67, 1.27)
Total	30.3 (498/1641)	33.8 (543/1605)	.035	1.17 (1.01, 1.36)
Total without D	35.1 (260/740)	37.9 (256/676)	.294	1.12 (0.90, 1.41)

Note: Data are % (n/N) unless otherwise specified. Cochran-Mantel-Haenszel test: P = .020 (evidence that OR $>$1). Mantel-Haenszel test: common OR = 1.20, with 95% CI (1.03, 1.39). Breslow-Day test: P = .156 (no evidence of heterogeneity of ORs between strata).
[a]Fisher's exact test (two-sided).

Table 5 Hospital discharge

Site	Control	Intervention	P^a	OR (95% CI)
A	8.2 (8/97)	16.5 (15/91)	.118	2.20 (0.82, 6.30)
B	10.8 (14/130)	16.0 (16/100)	.323	1.58 (0.68, 3.70)
C	7.9 (12/151)	14.0 (22/157)	.103	1.89 (0.85, 4.35)
D	11.4 (103/901)	13.2 (123/929)	.256	1.18 (0.89, 1.58)
E	8.0 (29/362)	10.7 (35/328)	.239	1.37 (0.79, 2.39)
Total	10.1 (166/1,641)	13.1 (211/1605)	.007	1.34 (1.08, 1.68)
Total without D	8.5 (63/740)	13.0 (88/676)	.007	1.61 (1.13, 2.30)

Note: Data are % (*n/N*) unless otherwise specified. Cochran-Mantel-Haenszel test: $P = .010$ (evidence that OR >1). Mantel-Haenszel test: common OR = 1.34, with 95% CI (1.08, 1.68). Breslow-Day test: $P = .591$ (no evidence of heterogeneity of ORs between strata).
[a]Fisher's exact test (two-sided).

arrest rhythm of VF/ventricular tachycardia (Table 6). In the control group, 20.0% of patients survived with an initial rhythm of VF/ventricular tachycardia versus 32.3% in the intervention group ($P < .001$; OR 1.91, CI [1.37, 2.68]). There was a dominant effect from site D, where survival rates for patients presenting with VF/ventricular tachycardia increased by 50%.

Patients who did not have VF as the initial rhythm had hospital discharge rates of 6.8% in the control group versus 7.1% in the intervention group ($P = .751$; Table 7). However, there was a wide range of differences between control and intervention groups by site for patients with initial non-VF rhythms.

Neurological outcome data (CPC score at the time of hospital discharge) were available from three of five sites (complete data from sites A and C and partial data from site D). Pooled data are shown at the top of Table 8. The denominator for each group in that table was the total number of survivors who were discharged from the hospital. A CPC score of 1 or 2 was considered favorable: CPC 1 means good cerebral performance, CPC 2 means moderate cerebral disability with sufficient cerebral function for independent activities of daily life, CPC 3 means severe cerebral disability with the need to rely on others for daily support because of impaired brain function (ranges from ambulatory to severe dementia and paralysis), and CPC 4 means comatose. The bottom part of Table 8 demonstrates the impact of the new intervention when the total number of patients who met enrollment criteria was used as the denominator instead.

Discussion

The results from this study are the most comprehensive to date regarding the impact of the 2005 AHA CPR Guidelines changes on clinical outcomes from out-of-hospital cardiac arrest. Implementing a number of simple changes based on prior clinical[1,3,4,7,9–11,13–15] and animal[3,4,6,8,12] studies to increase circulation during CPR resulted in a nearly 30% relative increase in hospital discharge rates for all patients in cardiac arrest. It is important to recognize that the hospital discharge rates during the control phase were nearly twice the reported national average.[17] Thus, the additional improvement associated with new CPR implementation may be even more clinically significant. It is also important to emphasize that there were large differences between sites in baseline hospital discharge rates and hospital discharge rates after the new intervention. Similar differences by geographic region were recently reported for 10 North American sites participating in the National Institutes of Health Resuscitation Outcomes Consortium.[17] These large, regional variations are thought to be multifactorial and include differences in patient demographics, quality of CPR, training and experience of first responders and ALS personnel, the frequency of bystander CPR, and time between arrest and the start of CPR by professional responders.[17] These variables were not assessed or controlled from site to site in the present study. As such, the improvements seen with these new interventions represent the potential generalized effectiveness of this approach.

Table 6 Hospital discharge VF/ventricular tachycardia patients only

Site	Control	Intervention	P^a	OR (95% CI)
A	26.3 (5/19)	50.0 (10/20)	.191	2.80 (0.61, 13.65)
B	23.3 (7/30)	30.3 (10/33)	.581	1.43 (0.41, 5.23)
C	12.0 (6/50)	21.1 (12/57)	.301	1.96 (0.61, 6.90)
D	19.5 (42/215)	33.5 (64/191)	.002	2.08 (1.29, 3.35)
E	22.5 (23/102)	33.7 (28/83)	.100	1.75 (0.87, 3.54)
Total	20.0 (83/416)	32.3 (124/384)	<.001	1.91 (1.37, 2.68)
Total without D	20.4 (41/201)	31.1 (60/193)	.016	1.76 (1.09, 2.87)

Note: Data are % (*n/N*) unless otherwise specified. Cochran-Mantel-Haenszel test: $P < .001$ (evidence that OR >1). Mantel-Haenszel test: common OR = 1.94, with 95% CI (1.39, 2.73). Breslow-Day test: $P = .940$ (no evidence of heterogeneity of ORs between strata).
aFisher's exact test (two-sided).

Table 7 Hospital discharge non-VF/ventricular tachycardia patients

Site	Control	Intervention	P^a	OR (95% CI)
A	3.8 (3/78)	7.0 (5/71)	.479	1.89 (0.35, 12.61)
B	7.0 (7/100)	9.0 (6/67)	.770	1.31 (0.34, 4.78)
C	5.9 (6/101)	10.0 (10/100)	.311	1.76 (0.55, 6.13)
D	8.9 (61/686)	8.0 (59/738)	.568	0.89 (0.60, 1.32)
E	2.3 (6/260)	2.9 (7/245)	.783	1.25 (0.35, 4.55)
Total	6.8 (83/1225)	7.1 (87/1221)	.751	1.06 (0.76, 1.46)
Total without D	4.1 (22/539)	5.8 (28/483)	.245	1.45 (0.79, 2.69)

Note: Data are % (*n/N*) unless otherwise specified. Cochran-Mantel-Haenszel test: $P = .808$ (no evidence that OR >1). Mantel-Haenszel test: common OR = 1.04, with 95% CI (0.75, 1.44). Breslow-Day test: $P = .652$ (no evidence of heterogeneity of ORs between strata).
[a]Fisher's exact test (two-sided).

Less than 25% of the patients in this study presented with an initial rhythm of VF/ventricular tachycardia. However, the greatest impact of new CPR was observed in this patient population, despite site-to-site variability in the effect of the new interventions on initial cardiac arrest rhythm. When the site with the largest number of patients, site D, was eliminated, there was still a significant improvement in hospital discharge rates for all patients regardless of the initial rhythm (8.5 vs. 13.0%, $P = .007$; OR 1.61; CI [1.13, 2.30]).

Neurological outcome data were available for nearly half of the patients who survived to hospital discharge. Neurological outcome was improved over 75% in the intervention group compared with controls (59.6% vs. 33.3%, $P = .038$; OR 2.95; CI [1.05, 8.50]). This is consistent with the impact of enhanced circulation during CPR, in part due to application of the hemodynamic principle of negative intrathoracic pressure seen with use of the ITD.[13–15] Negative intrathoracic pressure, generated on the upstroke of chest compression in the presence of the ITD, reduces intracranial pressure at a faster rate (than without use of the ITD), allowing for a greater duration of time when intracranial pressures are at their nadir, thereby improving mean arterial pressure and cerebral perfusion pressure during CPR.[1,16,18–20] Initial animal studies using the ITD with high-quality standard CPR demonstrated a significant improvement in neurological outcome in pigs.[12] The present study in humans with new CPR appears to validate this physiological principle and initial animal results.[1,12] To our knowledge, this is the first report of a series of CPR interventions resulting in a significant increase in survival as well as in neurological outcome for patients with cardiac arrest.

All sites emphasized the importance of proper CPR technique including the use of the recommended chest compression rate, depth, and complete chest recoil. EMS providers were taught to lift the heel of the hand slightly but completely off the chest at the end of each decompression during CPR. Previous study in animals has demonstrated that incomplete chest recoil increases intrathoracic pressure and decreases mean arterial, coronary, and cerebral perfusion pressures.[8] Lifting the heel of the hand slightly but completely off the chest at the end of decompression has been shown in manikin studies to result in a high incidence of complete chest recoil compared with the standard AHA hand position.[7,9] This is the first report in humans demonstrating a significant improvement in ROSC by incorporating this technique into a series of interventions focused on improving hemodynamics during CPR. It is important to note that all sites also emphasized push hard and fast, part of the 2005 AHA Guidelines recommendation to assure adequate chest compression.

These data are also consistent with a growing school of thought that the most effective treatment for this leading cause of death in the United States requires a multifactorial approach, similar to the treatment of other fatal diseases like heart failure or cancer. As such, each new intervention appeared to work synergistically to improve vital organ perfusion during CPR. In many ways these data represent just the first steps toward realizing the goal of >30% neurologically intact survival after cardiac arrest for all patients. We anticipate that use of therapeutic hypothermia[21,22] as well as regionalized systems of care, when coupled with the new interventions evaluated in the present study, will lead to an additional incremental gain in survival rates and neurological outcome.[21–25] Furthermore, mechanical devices, such as those used to further augment the clinical utility of the ITD by actively decompressing the chest, were not used in these patients.[12,26] Taken together, these multiple concurrent and sequential interventions pro-

Table 8 No. and percentage of patients discharged with CPC scores of 1 or 2

Site	Control	Intervention	P^a	OR (95% CI)
Denominator includes all patients discharged alive				
3 Sites	33.3 (10/30)	59.6 (31/52)	0.038	2.95 (1.05, 8.50)
Denominator includes the total no. of treated patients who met enrollment criteria				
3 Sites	3.1 (10/325)	9.2 (31/336)	0.001	3.20 (1.49, 7.44)

Note: Data are % (*n/N*) unless otherwise specified.
[a]Fisher's exact test (two-sided).

vide a blueprint for optimal present and future care for patients with out-of-hospital cardiac arrest.

This evaluation has limitations. The investigation used the only appropriate clinical control groups possible when evaluating the impact of AHA recommendations and, as such, is subject to the limitations and potential confounders of historical controls and heterogeneity between sites. The study was not blinded, as blinding is not possible with use of these CPR techniques. Second, it is not possible to determine which aspects of the new intervention had the most impact on overall survival rates, since each intervention that enhances circulation affects the next. Nonetheless, the consistency of the overall benefit across EMS systems adds to the generalizability of the results. As noted above, the investigators believe that no single therapy alone is primarily responsible for improved outcome for this complex disease state. Just as it was shown that widespread implementation of automatic external defibrillators on all EMS vehicles in Seattle[27] resulted in a decrease in survival rate (when deployed without CPR before defibrillation), the current data support the hypothesis that multiple sequential therapies are needed to significantly improve survival rates. Third, there were differences in the baseline absolute ROSC and hospital discharge rates from site to site. However, analysis of the data using the Breslow-Day test, the Mantel-Naenszel test, and the Cochran-Mantel-Haenszel test support the hypothesis that the improved outcome of the 2005 AHA Guildelines interventions described herein can be generalized, despite baseline differences in survival rates from site to site.

One final limitation should be noted. Two of the sites (A and E) implemented all of the aspects of the 2005 AHA Guidelines described in Table 1 except the ITD in 2005. Thus, the data described as historical control data herein included many of the 2005 guideline changes to augment circulation during CPR, minus the ITD. As such, the survival impact of all of the interventions described may actually be underestimated in this report.

Conclusion

In conclusion, compared with controls, patients with out-of-hospital cardiac arrest treated with new CPR as recommended by the 2005 AHA Guidelines (e.g., renewed emphasis on more hard and fast compressions, fewer ventilations, the ITD, and complete chest wall recoil) had significantly higher neurologically intact hospital discharge rates. These findings support the importance of implementing an optimized sequence of therapeutic interventions during the performance of CPR for patients in cardiac arrest.

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