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CARDIOCEREBRAL RESUSCITATION

Cardiocerebral Resuscitation Improves Survival of Patients with Out-of-Hospital Cardiac Arrest

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ABSTRACT

PURPOSE: The guidelines for cardiopulmonary resuscitation (CPR) have been in place for decades; but despite their international scope and periodic updates, there has been little improvement in survival rates in out-of-hospital cardiac arrest for patients who did not receive early defibrillation. The Emergency Medical Service directors in 2 rural Wisconsin counties initiated a new protocol for the pre-hospital management of adult cardiac arrest victims in an attempt to improve survival rates. The results observed after implementation of this protocol are presented and compared with those observed during a three-year period that preceded initiation of the project.

METHODS: The protocol, based upon the principles of cardiocerebral resuscitation, was significantly different from the standard CPR protocol. A major objective was to minimize interruptions of chest compressions. Each defibrillation, including the first, was preceded by 200 uninterrupted chest compressions. Single shocks, rather than stacked shocks, were utilized. Post shock rhythm and pulse checks were eliminated, and chest compressions were resumed immediately after a shock was delivered. Initial airway management was limited to an oral pharyngeal device and supplemental oxygen. If the arrest was witnessed, assisted ventilations and intubation were delayed until either a return of spontaneous circulation or until three series of "compressions + analysis ± shock" were completed.

RESULTS: In the 3 years preceding the change in protocol, where standard CPR was utilized, there were 92 witnessed out-of-hospital adult cardiac arrests with an initially shockable rhythm. Eighteen patients survived, and 14 of 92 (15%) were neurologically intact. After implementing the new protocol in early 2004, there were 33 witnessed out-of-hospital adult cardiac arrests with an initially shockable rhythm. Nineteen survived, and 16 of 33 (48%) were neurologically normal. Differences in both total and neurologically normal survival are significant (chi-squared = 0.001).

CONCLUSION: Instituting the new cardiocerebral resuscitation protocol for managing prehospital cardiac arrest improved survival of adult patients with witnessed cardiac arrest and an initially shockable rhythm.

Out-of-hospital cardiac arrest is second only to all cancer deaths combined as a cause of mortality and is responsible for approximately 490 000 deaths a year in the United States.[1] In the absence of early defibrillation, survival rates are dismal and have remained essentially unchanged for almost four decades in spite of periodic updates of standardized guidelines.[2,3]

In November 2003, the Sarver Heart Center Cardiopulmonary Research Group at the University of Arizona, in cooperation with the Tucson Fire Department, instituted a new approach to out-of-hospital cardiac arrest.[4-6] This approach, now referred to as cardiocerebral resuscitation (CCR), was significantly different in many aspects from standard cardiopulmonary resuscitation (CPR). A revised version of cardiocerebral resuscitation was instituted in two rural counties in Wisconsin in early 2004.[7] The details of this Wisconsin project and the survival rates observed after its implementation are presented.

METHODS

In late 2003, the 4 emergency medical service (EMS) medical directors in 2 rural Wisconsin counties sent represen-

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tatives to Tucson, Arizona to study the details of their program. The evidence presented convinced them that changing from the then-standard CPR protocol to a CCR protocol might result in improved survival in the patient population they served.[4,7] After planning and protocol development, and EMS and law officer education, the new prehospital protocol was implemented by the EMS directors as a demonstration project for the purpose of improving survival in adult out-of-hospital cardiac arrest victims. The project[7] was approved by the institutional review board of Mercy Health System; it also was approved for use by the Wisconsin Emergency Medical Services Bureau. The project was instituted in Rock and Walworth Counties in south central Wisconsin. Each of the four EMS regions instituted the new prehospital resuscitation protocol at different times in 2004: 1 in February, 1 in May, and 2 in June.

CLINICAL SIGNIFICANCE

- Survival rates in out-of-hospital cardiac arrest, which have been dismal and unchanged for 4 decades, can be dramatically improved.
- This was accomplished by changing prehospital emergency medical services treatment from standard CPR to protocols based upon the principles of cardiocerebral resuscitation.
- These changes included the use of simplified chest-compression-only CPR by emergency medical services and law officer first responders.

The cardiocerebral resuscitation or CCR approach was as follows: EMS and law officer personnel used a protocol consisting of 200 continuous chest compressions performed before rhythm analysis. If a shockable rhythm was present, a single shock, instead of multiple or stacked shocks, was given. The postshock pulse check and rhythm analysis were eliminated, and continuous chest compressions were initiated immediately following the shock. The technique of chest compressions was taught with an emphasis on a rate of 100 per minute, the use of a metronome to insure a proper chest compression rate, and emphasis upon full chest recoil after each compression. If only one responder was on the scene, the automated external defibrillator (AED) pads were attached before chest compressions were initiated. Pulse checks were performed during rhythm analysis with the location of the carotid pulse confirmed during the terminal period of chest compressions.

Airway management was also modified in the new CCR protocol. Initial airway management was delayed until a second rescuer arrived and then consisted only of the placement of an oral pharyngeal airway and administration of oxygen by nonrebreather mask. If the arrest was witnessed, and down time was less than 12 minutes, rescue breaths and assisted ventilations were not performed until after the return of spontaneous circulation or until after 3 cycles of chest compressions followed by rhythm analysis with or without a shock were completed. None of the patients received postarrest hypothermia.

This prehospital CCR protocol was to be used only in adults with a presumed cardiac arrest, that is, individuals with a sudden unexpected collapse with absent or abnormal breathing. Cases with a traumatic or presumed respiratory arrest were treated with the standard CPR protocol.[8]

Whenever possible, AEDs were programmed to deliver a single shock instead of stacked shocks and, if possible, a shock at maximum joules. They also were programmed, again if possible, to pause 2 minutes while the rescuer delivered continuous chest compressions.

The EMS response is functionally a 3-tiered system for cardiac arrest patients. First responders are involved in most cases. These first responders are radio-dispatched CCR-trained law officers or EMS personnel who most often are equipped with an AED. Second tier municipal nonparamedic ambulances are generally dispatched for each call. Paramedic squads, either as the primary responding unit or one called to assist in care, participate in all cardiac arrest cases.

Rock and Walworth Counties have areas of 720 and 555 square miles, respectively. Their 2004 populations were 156 512 and 98 334, respectively. The single 911 center in Rock County gave standard CPR instructions to callers in the 2001-2003 period and chest-compression-only instructions after May of 2004. None of the three 911 centers in Walworth County gave CPR instructions. There were 582 first responder law officers in the 2 counties. Rock County had 2 municipal paramedic squads with 60 members, and Walworth County had 3 private paramedic squads with 50 members. The 22 municipal nonparamedic squads in the 2 counties had a total of 458 primarily volunteer emergency medical technicians (EMTs).

Data were collected retrospectively for cases treated during the 2001-2003 "control" period, when patients were treated utilizing the then-standard CPR protocol. Data were collected prospectively during the "project" period in early 2004 through May of 2005 after the institution of the new CCR protocol. Data for each of these periods was obtained from EMS run reports, 911 and dispatcher recordings, emergency department and hospitalization records and, when necessary, conversations with rescuers involved in a case and physicians caring for the patient. Defibrillator/AED downloads were available only during the study period. Individual charts were created for each patient during the protocol period.

An arrest was designated as "witnessed" if someone at the scene heard or saw the patient collapse. In a few instances, cases were considered witnessed if a definable activity of known brief duration (less than 1 or 2 minutes)

existed between last contact and collapse. Initial rhythms were categorized as shockable or nonshockable. "Call-to-shock" intervals were calculated using the time the 911 call was received and the time of the initial defibrillation attempt.

As presented in the Figure, cases were excluded from the analysis of survival for the following reasons: if prehospital treatment was either not initiated or was terminated in the field, if the patient had a Do-Not-Resuscitate order, if the etiology of the arrest was noncardiac, if the arrest was witnessed by an EMS rescuer at the scene, or if the patient was younger than 16 years of age. The neurological status of each survivor at hospital discharge was obtained using the Cerebral Performance Category (CPC) score.[9] Neurologically "normal" survival was defined as a CPC score of 1.

RESULTS

During the 3-year period when standard CPR was utilized there were 92 adult patients with witnessed cardiac arrests and an initially shockable rhythm. Eighteen of these 92 patients (20%) survived, and 14 of these 92 (15%) survived neurologically intact. After the CCR protocol was initiated, there were 33 such patients. Nineteen of these 33 patients (57%) survived, and 16 of the 33 (48%) survived neurologically intact. The differences in both total survival and neurologically normal survival are significant (Chi-squared = 0.001).

As shown in the Figure, the prevalence of arrests considered cardiac in origin, arrests that were witnessed, and arrests with a shockable initial rhythm were similar in the control and project groups. Although none of the patients who suffered an arrest in the presence of EMS personnel were included in the survival analysis, the prevalence in the two groups was also identical.

A comparison of call-to-shock times for patients who had a witnessed arrest and an initially shockable rhythm is presented in the Table. Among survivors, shocks were delivered within 7 minutes in 87% of patients during the standard CPR control period and in 47% of the patients during the CCR project period. By 10 minutes, all of the control survivors had been shocked, compared with 84% of project patients. Eight of the 69 control patients (12%) received an initial shock within 4 minutes, compared with 3 of 32 project patients (9%).

Table Call-to-Shock Data for Patients in the Control and Project Groups with a Witnessed Cardiac Arrest and an Initially Shockable Rhythm

	Number of cases per interval			
Call to shock	Alive		Died	
Interval (Min)	Project	Control	Project	Control
0				
1				
2		1		
3	1	1		
4	1	2	1	4
5	2	4	3	6
6	3	4	2	8
7	2	1	1	11
8	2		3	6
9	3	1		4
10	4	1	2	6
11				1
12	1		1	4
13				2
14				1
15				
16				1
No. with data	19	15	13	54
No. without data	0	3	1	20
Total no.	19	18	14	74

DISCUSSION

This is the first report of survival rates in out-of-hospital cardiac arrest where the principles of cardiocerebral resuscitation were employed in prehospital care.

Survival rates for adult patients with a witnessed arrest and an initially shockable rhythm were substantially improved after institution of the new CCR protocol.

A recently published model[10] of cardiac arrest due to ventricular fibrillation (VF) is helpful in discussing the new CCR protocol. This model points out that the pathophysiology of VF arrest changes rapidly with the passage of time; the effect of an intervention is then dependent upon when during the arrest it is applied. This model conceptualizes an arrest as consisting of three "time-dependent" phases defined by interventions considered crucial to ameliorating the underlying pathophysiology. During the first or "electrical" phase, which lasts about 4 minutes, the crucial intervention is defibrillation. During the second or "circulatory" phase, which lasts from about minute 4 to about minute 10 (but may last longer), the crucial intervention is the generation of adequate cerebral and coronary perfusion. The third or "metabolic" phase then follows.

During the first or "electrical" phase of arrest, which lasts about 4 minutes, the crucial intervention is defibrillation. This is why early defibrillation is effective in a wide variety of settings such as airports, airplanes, casinos, and in the community where AEDs are employed by bystanders and response times are minimal.[11-15] Early defibrillation was used in this project, when the arrest occurred in the presence of EMS responders, but these cases were not included in the "witnessed" groups in the survival analysis (Figure).

Immediate defibrillation was not advocated in the new CCR protocol; instead, defibrillation was delayed until 200 chest compressions (2 minutes) were performed. This is a significant deviation from standard CPR.[8] The three-phase time-dependent model of VF cardiac arrest[10] helps explain not only why this protocol change was made, but also what impact it may have had on survival. Rescuers seldom arrived during the first 4 minutes, where immediate defibrillation is considered the crucial intervention; instead, most

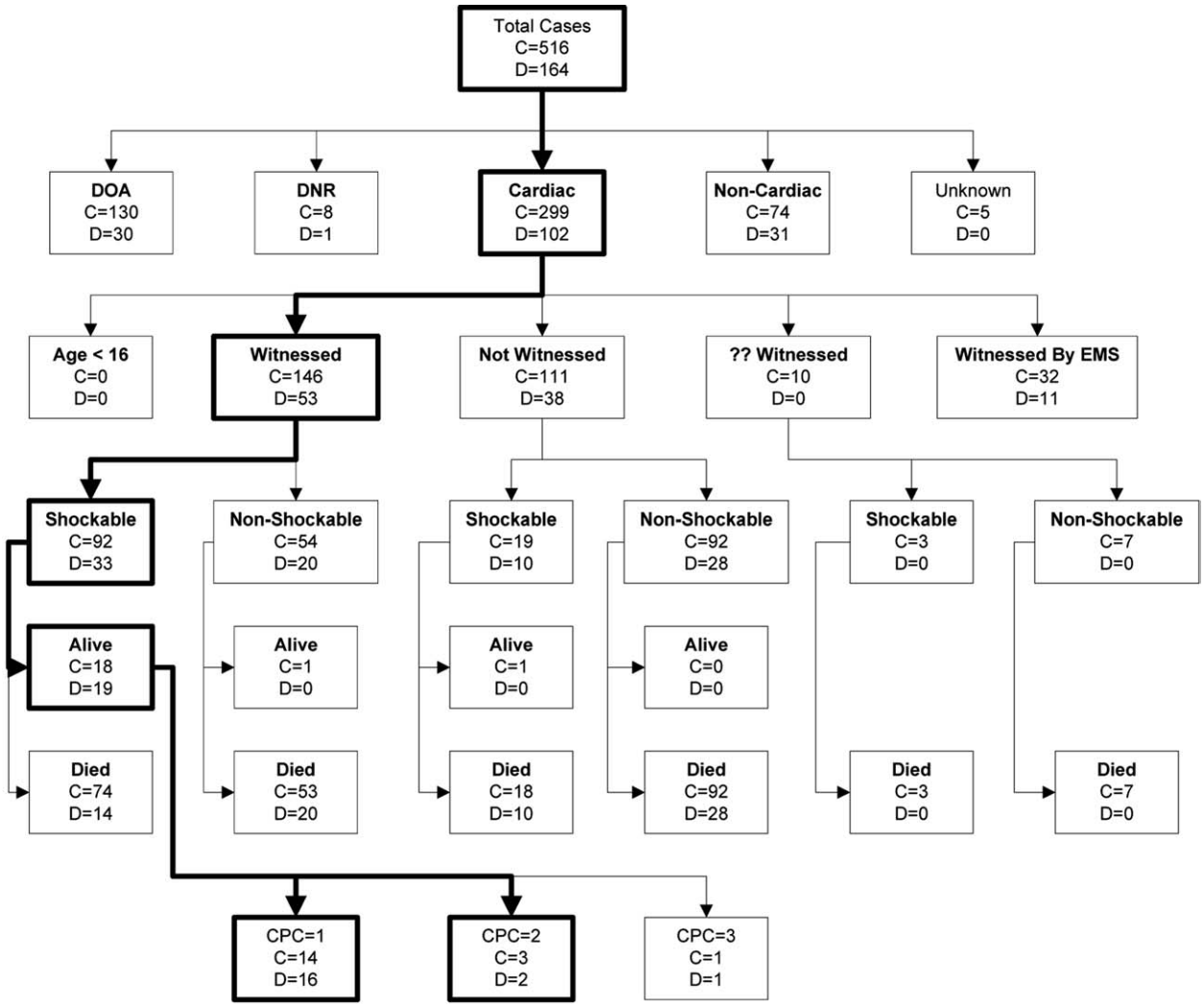

Figure 1 The number of patients in each subset of total cases is presented for the historical 2001-2003 control period (C) and the 2004-2005 demonstration project period (D). DOA cases were considered "dead-on-arrival" and resuscitation was either not initiated or was terminated in the field. DNR individuals had a valid do-not-resuscitate order in effect. The cause of an arrest was classified as Cardiac, Non-Cardiac or Unknown (information insufficient). An arrest was considered "Witnessed" if collapse was either seen or heard. Initial rhythms were designated as shockable or non-shockable. The neurologic CPC scores for survivors are presented.

arrived during the "circulatory" phase of arrest, from about minute 4 to about minute 10. During this phase, the crucial intervention is the generation of adequate cerebral and coronary perfusion by chest compressions before defibrillation. Unfortunately, immediate defibrillation can be counterproductive if employed in this "circulatory" phase, or later, if inadequate coronary perfusion exists.[4,16-18]

The third or "metabolic" phase is associated with very low survival rates.[10] Hypothermia is the most promising intervention during this phase. Hypothermia was not applied to any of the patients herein reported.

The protocol of cardiocerebral resuscitation included not only 200 continuous chest compressions before but also immediately after defibrillation.[4,5,7] The reason for the former is based on two reports of increased survival when defibrillation was preceded by a period of CPR. Wik and associates[18] used 3 minutes of CPR, and Cobb and associates[19] used 90 seconds of CPR before defibrillation. The rationale for immediately resuming chest compressions after the single shock is that defibrillation often converts the patient's rhythm to asystole or pulseless electrical activity.[4] Both of these rhythms require adequate coronary perfusion if the patient is to return to a perfusing rhythm.[4,5] If chest compressions are not promptly administered, pulseless electrical activity soon deteriorates into ventricular fibrillation or asystole.[4]

The project's CCR protocol emphasized the crucial nature of minimizing interruptions of chest compressions. Such interruptions were to occur only during the switching of personnel performing chest compressions or during rhythm analysis and defibrillation. Prolonged periods of interrupted chest compressions during AED rhythm analysis were avoided by delivering a single shock instead of stacked shocks. Pulse checks were advocated during the rhythm analysis period, a time when chest compressions were already being temporarily interrupted. Locating the carotid

pulse was done just before rhythm analysis, and, therefore, the pulse without compressions could rapidly be determined. Single rescuers equipped with an AED avoided a prolonged pause between stopping chest compressions and defibrillation by applying the AED pads before initiating chest compressions.

At the time these observations were made, the resuscitation guidelines[20] recommended up to three "stacked shocks, without intervening chest compressions" to achieve defibrillation. The guidelines also recommended immediate postdefibrillation pulse checks. The CCR protocol deviated from these recommendations.[4-7] Instead of stacked shocks, a single shock was utilized. As mentioned above, postshock pulse checks were also eliminated. Rea et al[21] recently reported that the activities of rhythm reanalysis, stacked shocks, and initial postshock pulse checks resulted in an approximately 30-second delay in reinstitution of chest compressions after shocks when AEDs were used. Postshock pulse checks generated useful information in only 1 of 50 patients. They found that these activities resulted in a low yield with regard to the balance between achieving or detecting a pulse and initiating CPR. They concluded that, "one consideration would be to eliminate these activities from the resuscitation algorithm."[21]

The CCR protocol's airway and ventilation management represented another major deviation from the current guidelines.[8] Rescue breaths and assisted ventilation were not performed during the initial phases of treatment for patients with witnessed arrest and an initially shockable rhythm. During the initial phase of a VF cardiac arrest, the pulmonary veins, heart, and the entire arterial system is filled with oxygenated blood. The goal of the CCR protocol was to maximize time spent in circulating this oxygenated blood to the brain and the heart. Studies of out-of-hospital cardiac arrest in Europe have reported that bystander chest-compression-only CPR resulted in outcomes similar to that of standard CPR where ventilations were added to compressions.[22-24] Animal studies indicate that interruptions of chest compressions to provide rescue breaths diminishes survival. When chest-compression-only CPR was compared with standard CPR performed with a realistic 16 seconds to deliver the 2 breaths, survival was substantially better with chest-compression-only CPR.[25]

The CCR protocol also eliminated assisted ventilation in the initial phases of prehospital EMS treatment.[7] Instead, airway patency was ensured and supplemental oxygen was applied via nonrebreather mask. The rationale for this approach is provided by studies demonstrating that positive pressure ventilations increase intra-thoracic pressures, reduce venous return, decrease cerebral and cardiac perfusion pressures, decrease the success of subsequent defibrillation, and decrease the survival rates in animal models.[4,5,26-30] Limited ventilations may be of benefit, but published observations indicate that once ventilations are initiated, they are almost always performed at rates far in excess of recommended rates.[29,31] The improved survival herein reported supports limiting positive pressure ventilations during the initial phase of treatment of patients with a witnessed arrest and an initially shockable rhythm.

Continuous-chest-compression CPR is far easier to teach, learn, and recall; additionally, the training time is substantially reduced when compared with standard basic CPR. This was observed in our law officer training sessions. Additionally, it was our clear impression that the law officer first responders were substantially more receptive to a form of CPR that did not involve mouth-to-mouth ventilation. For this and the reasons mentioned above regarding airway management and elimination of assisted ventilation, EMS responders utilized continuous-chest-compression CPR. We also advocate it for layperson training because these individuals often intervene during the initial phases of cardiac arrest when perfusion is more critical than additional oxygenation.[4-6]

This report has limitations. First and foremost, it is an observational report with historical controls. The observed improvement in survival must therefore be viewed as preliminary rather than definitive; one that needs to be confirmed by controlled trials. Because the project was implemented by the EMS medical directors for the purpose of improving survival, multiple interventions were introduced at the same time. It is therefore not possible to discern the survival advantage attributable to any one of the given interventions.

Secondly, all but one of the project patients was defibrillated within 10 minutes of the 911 call. The applicability of the cardiocerebral resuscitation protocol to patients where EMS interventions are initiated after 10 minutes needs to be addressed in future studies. This is particularly important with regard to delaying active airway interventions and ventilations for three chest-compression-shock cycles. It is of interest that one patient in the project group, with a call-to-shock time of 12.8 minutes, survived neurologically intact.

Thirdly, the effect of the CCR protocol upon survival in cases where the arrest is not witnessed or the initial rhythm is not shockable, cannot be determined. During the CCR protocol period, advanced airway control and intravenous medications were initiated as soon as rescuers with appropriate training and skills arrived. Survival in this group of patients is so low that a much larger study would be needed to delineate the impact of utilizing the CCR protocol before skilled rescuers arrived.

It is possible that the improved survival rates observed in this report are in part due to the Hawthorne effect, that is, improvement attributable not to the cardiocerebral resuscitation protocol, but rather to knowledge by the participants that they were being observed in connection to outcomes. There is no question that there was a change in attitude among the law officer and EMS personnel. They realized that these patients *can* be resuscitated and, as a result, their expectations and perhaps performance improved. Only long-term follow-up will determine what role the Haw-

thorne effect may have played, if any, in the improved survival rates observed.

This report is the first observation in man that survival from out-of-hospital witnessed cardiac arrest is enhanced by the new paradigm of cardiocerebral resuscitation. Further observational or randomized controlled studies will be necessary to confirm these preliminary observations.

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