Cardiocerebral Resuscitation : The New Cardiopulmonary Resuscitation

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Special Report

Cardiocerebral Resuscitation
The New Cardiopulmonary Resuscitation

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"Why is it that every time I press on his chest he opens his eyes, and every time I stop to breathe for him he goes back to sleep?"[1]

This article reviews research that shows that cardiopulmonary resuscitation (CPR) as it has been practiced and as it is presently taught and advocated is far from optimal. *The International Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care,* hereafter referred to as "Guidelines 2000," were evidence based.[2] During their formulation, the greatest weight of evidence was given to placebo-controlled randomized trials in humans. Unfortunately, it is extremely difficult not only to obtain informed consent but also to obtain funding for studies of the magnitude necessary to answer critically important CPR questions. It is unfortunate that controlled CPR research in animals was given the lowest priority in the evidence-based scheme.[2] In our opinion, controlled animal experiments provide data that may be nearly impossible to obtain in human trials in which the circumstance, age, disease states, interventions, and response times to arrest are variable and often unknown. On the other hand, the use of swine for CPR research is not the perfect experimental solution, because they are easier to resuscitate in that they have no underlying heart disease (unless experimentally produced), they are younger, and they have more compliant chests than older adults with cardiac arrest.

Since the formulation of "Guidelines 2000," old and new research in animals and new research in humans have rendered them outdated. Although they will be revised, it is unknown when and what changes will be made. Nevertheless, in 2003, the CPR research information from both animal and humans was so compelling that we could not in good conscience wait for yet another set of new guidelines. Accordingly, our CPR research group, in cooperation with the Tucson Fire Department, initiated a new comprehensive resuscitation program in November 2003 in Tucson, Ariz, with emphasis on these new research findings.[3] We were encouraged in this effort by our colleagues in Europe,[4] and, as noted below, recent studies in humans have reinforced our conclusions.

Three Phases of Cardiac Arrest Due to Ventricular Fibrillation

One of the many important concepts to come forward since "Guidelines 2000" were published is the 3-phase, time-dependent concept of cardiac arrest due to ventricular fibrillation articulated by Weisfelt and Becker.[5] The first phase is the electrical phase, which lasts ≈5 minutes. During this phase, the most important intervention is prompt defibrillation. This is why the benefit of the automatic external defibrillator (AED) has been shown in a wide variety of settings, including airplanes, airports, casinos, and in the community.[6–10] The second phase of cardiac arrest due to ventricular fibrillation is the hemodynamic phase, which lasts for a variable period of time, but possibly from minute 5 to minute 15 of the arrest. During this time, generation of adequate cerebral and coronary perfusion pressure is critical to neurologically normal survival; however, if an AED is the first intervention applied during this phase, the subject is much less likely to survive for reasons that will be presented below. The third phase is the metabolic phase, for which innovative new concepts are needed, the most promising of which is the application of hypothermia. An appreciation of these 3 phases helps one put into context some of the recent findings in resuscitation research.

Physiology of Resuscitation From Cardiac Arrest

The opening quote above is from a woman who had been given 9-1-1 dispatch telephone instructions in cardiopulmonary resuscitation.[1] It is more than a decade old, but when I listened to this recording, I could not help but marvel at the importance of the observation made by this distraught woman trying to resuscitate her husband while awaiting the arrival of the paramedics. She correctly observed what our and others' research had found: that during cardiac arrest, maintenance of cerebral perfusion is critical to neurological function. During the hemodynamic phase, the most important determinant of cerebral perfusion is the arterial pressure generated during external chest compressions.[11–15] This perfusion pressure is lost when one stops chest compressions for rescue breathing.[11–15] The same can be said for maintaining viability of the fibrillating heart. The fibrillating ventricle can be maintained for long periods of time if there is adequate coronary or

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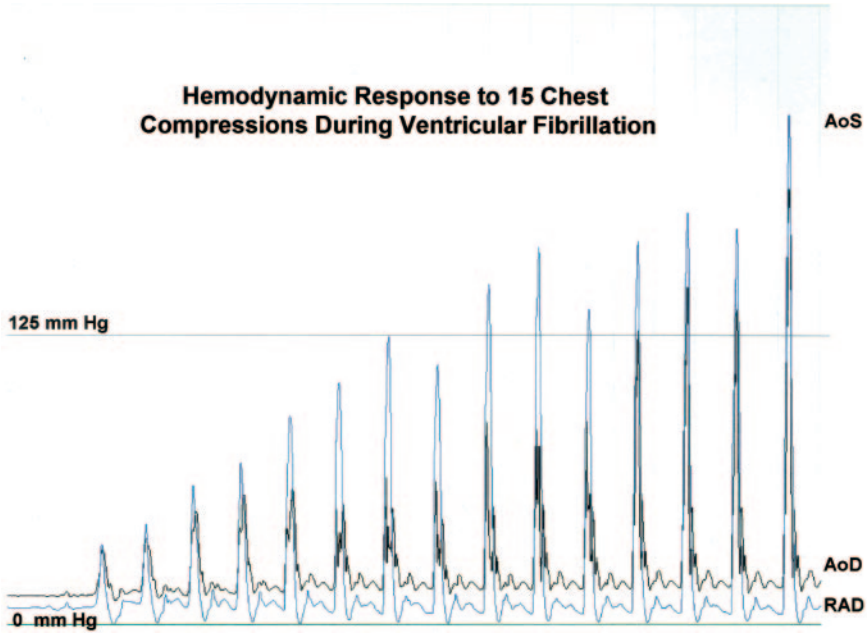

Figure 1. Simultaneous recording of aortic and right atrial pressures during first 15 external chest compressions in swine in cardiac arrest due to ventricular fibrillation. AoS indicates aortic "systolic" pressure during chest compression; AoD, aortic "diastolic" pressure during release phase; and RAD, right atrial pressure during "diastolic" or release phase of chest compression.

myocardial perfusion pressure produced and the coronary arteries are open. If early defibrillation is not available, a major determinant of survival from ventricular fibrillation cardiac arrest is the production of adequate coronary perfusion pressure.[11–15] The coronary perfusion pressure is the difference between the aortic "diastolic" pressure and the right atrial "diastolic" pressure. The word diastolic is in quotes because CPR "systole" is the chest compression phase, and CPR "diastolic" is the release phase of external chest compression (Figure 1). As shown in Figure 1, once chest compressions are begun, it takes time to develop cerebral and coronary perfusion pressures. When chest compression is interrupted for rescue breathing, the cerebral perfusion pressure drops abruptly, and the cardiac perfusion pressure drops significantly. During single-rescuer scenarios, it takes time for the cerebral and coronary perfusion pressures to increase with chest compressions, only to fall each time they are interrupted for ventilation.[16]

These perfusion pressures are important. It has been shown that during prolonged cardiac arrest, survival in animals (Figure 2) and return of spontaneous circulation in humans are related to the coronary perfusion pressures generated during chest compression.[15,17] There are several other major determinants of the perfusion pressure during closed-chest compression in cardiac arrest, including vascular resistance, vascular volume, and intrathoracic pressure. The importance of the vascular resistance during chest compression explains why vasopressors may improve perfusion pressures and vasodilators decrease perfusion pressures.[18–21] The effective intravascular volume is also critical, because an adequate perfusion pressure cannot be obtained and patients cannot be resuscitated if the vascular volume is low. Causes of low vascular volume include excessive blood loss and vascular fluid extravasation. Marked dilation of the venous system may also result in an effective low blood volume. The intrathoracic pressure is yet another determinant of perfusion pressure. A low or negative intrathoracic pressure during the "diastolic" or release phase of chest compression helps to augment venous return into the chest.[22] A high intrathoracic pressure during the relaxation or "diastolic" phase of chest compression inhibits venous return. Thus excessive ventilation, as will be detailed below, will decrease venous return to the thorax and decrease survival.[23]

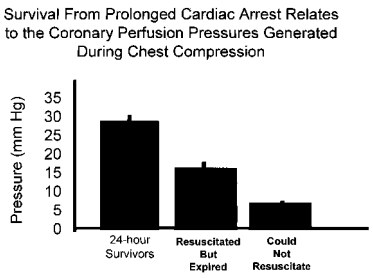

Figure 2. Survival from prolonged cardiac arrest in canines relates to coronary perfusion pressure generated during external chest compressions. See text.

However, there is a distinct window of time in which the perfusion pressure must be restored. Excellent perfusion pressures supplied too late (after the hemodynamic phase and during the metabolic phase) will not resuscitate the subject because irreversible tissue and organ damage has occurred.[14] An appreciation of the physiology of closed-chest resuscitation from cardiac arrest facilitates understanding of the research findings to be presented below.

Lack of Bystander-Initiated CPR

The first problem contributing to the dismal survival rates of out-of-hospital cardiac arrest is the lack of bystander- or citizen-initiated basic CPR. Although the majority of out-of-hospital cardiac arrests are witnessed, only 1 in 5 receive bystander- or citizen-initiated CPR.[24–26] A survey by our CPR Research Group indicated that only 15% of lay individuals would definitely do mouth-to-mouth resuscitation on a stranger.[27] Anonymous surveys have shown that lay individ-

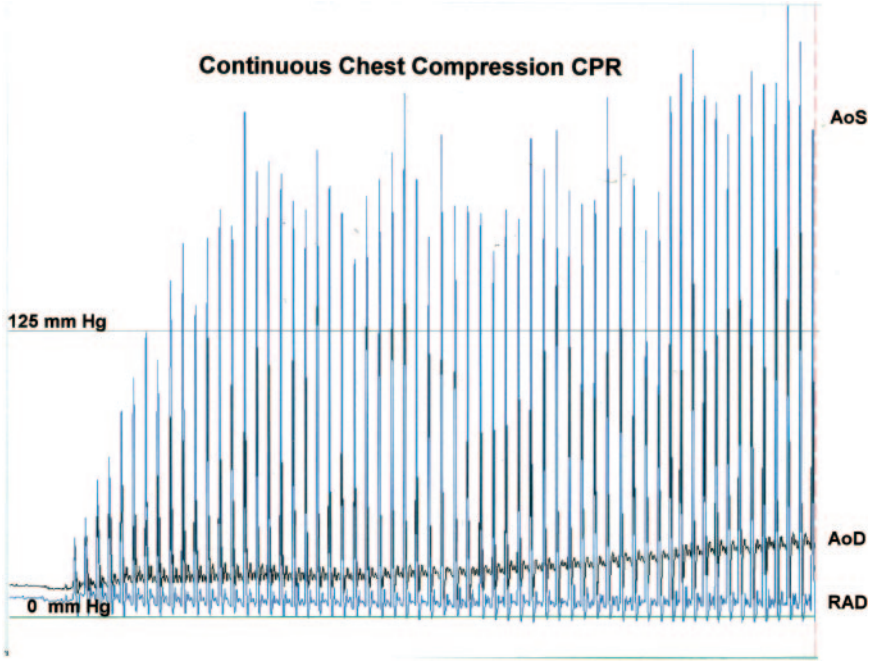

Figure 3. Simultaneous recording of aortic and right atrial pressures during continuous external chest compressions in swine in cardiac arrest due to ventricular fibrillation. AoS indicates aortic "systolic" pressure during chest compression; AoD, aortic "diastolic" pressure during release phase; and RAD, right atrial pressure during "diastolic" or release phase of chest compression.

uals are not the only ones reluctant to provide mouth-to-mouth resuscitation on strangers—so are certified CPR instructors and physicians.[28–31] Yet, in the absence of early defibrillation, bystander- or citizen-initiated chest compression is essential for improved survival for patients with out-of-hospital cardiac arrest.[32] A meta-analysis published in 1991 of 17 studies showed that individuals receiving bystander CPR were 4.5 times more likely to survive.[33] Since then, other studies confirmed the importance of bystander-initiated CPR for out-of-hospital sudden cardiac arrest victims.[24] In another study, those who received bystander-initiated CPR were 3 times more likely to survive to leave the hospital.[25] And a recent report from a 20-community study of adult out-of-hospital cardiac arrest found that citizen-initiated CPR was strongly associated with increased survival and better quality of life.[26] Yet, early bystander CPR is not being done, principally because of the bystander's reluctance to perform mouth-to-mouth rescue breathing. This information, along with our research findings, led us to ask whether chest-compression–only CPR, eg, without mouth-to-mouth rescue breathing, was better for out-of-hospital cardiac arrest than doing nothing until the paramedics arrived.

We compared 24-hour survival with 3 different approaches to bystander CPR using a swine model of prehospital single-rescuer CPR. The 3 interventions were chest-compression–only CPR, "ideal" standard CPR, and no bystander CPR.[1] The ideal standard CPR group was ventilated with hand-bag-valve ventilation via an endotracheal tube with 17% oxygen and 4% carbon dioxide, with 2 ventilations delivered within 4 seconds before each set of 15 chest compressions, to simulate "ideal" mouth-to-mouth rescue breathing. After one-half minute of untreated ventricular fibrillation, the swine were randomized. After 12 minutes of intervention (total duration of ventricular fibrillation 12.5 minutes), advanced cardiac life support was supplied, simulating the late arrival of paramedics. We found that all animals in both the chest-compression–only CPR (Figure 3) and the ideal standard CPR (Figure 4) groups were resuscitated successfully and were neurologically normal at 24 hours. In sharp contrast, only 2 of 8 animals in the group that had no chest compressions until 12.5 minutes (simulating no bystander CPR and the late arrival of emergency medical personnel) survived, and 1 of the 2 was comatose and unresponsive.[1] Our University of Arizona Sarver Heart Center CPR Research Group has published 6 studies with a total of 169 swine with variable durations of ventricular fibrillation arrest before initiation of basic life support (BLS), and various durations of "ideal" standard BLS and chest-compression–only BLS.[1,14,34–38] We found that chest-compression–only BLS and ideal standard BLS resulted in similar 24- or 48-hour normal or near-normal neurological survival and that both were dramatically better than simulated no-bystander–initiated BLS and late arrival of paramedics (Figure 5).[1,14,34–38] Others have confirmed these findings.[39]

These findings were enough for us to encourage bystander continuous-compression CPR without mouth-to-mouth rescue breathing for witnessed cardiac arrest in adults, eg, nonrespiratory cardiac arrests; however, "Guidelines 2000" did not make this recommendation. Although not previously willing to extend such a recommendation for everyone doing bystander-initiated CPR, American Heart Association guidelines have stated that, "If a person is unwilling to perform mouth-to-mouth ventilation, he or she should rapidly attempt resuscitation, omitting mouth-to-mouth ventilation."[40,41] Unfortunately in American Heart Association– and Red Cross–sponsored CPR courses, chest-compression–only CPR is rarely, if ever, mentioned.

After publication of "Guidelines 2000," a pivotal finding was reported from England.[42] Dr Karl Kern, a member of our CPR research group, was a coauthor of this study.[42] Videos of lay individuals doing CPR on manikins documented that it takes them an average of 16±1 seconds to deliver the "Guidelines 2000"–recommended 2 breaths.[42] Accordingly,

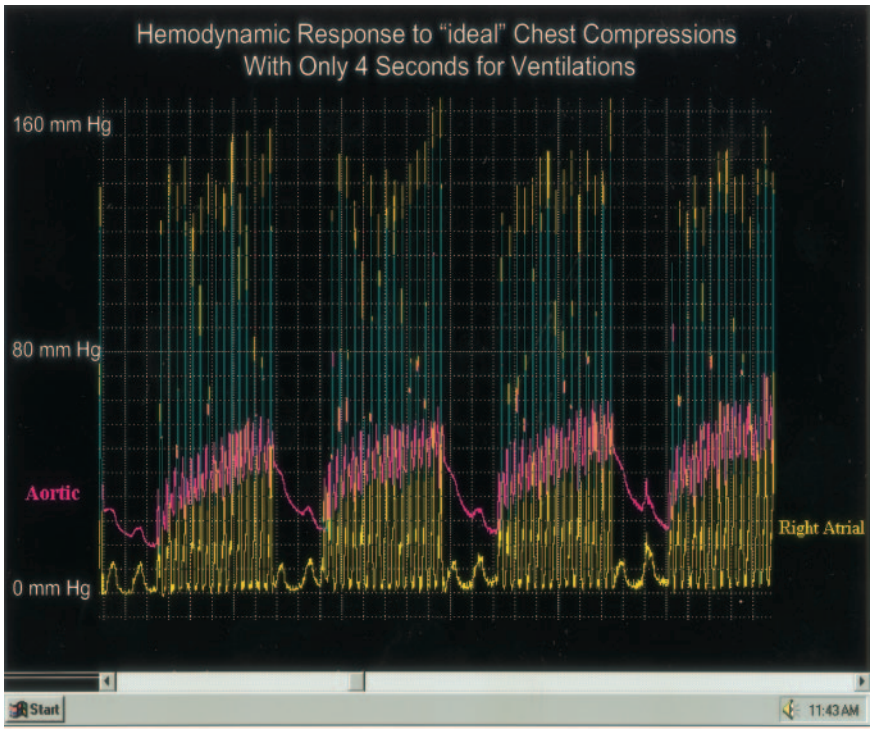

Figure 4. Simultaneous recording of aortic diastolic (red) and right atrial (yellow) pressures during CPR in which 2 ventilations are delivered within 4-second time period.

we conducted another experiment in swine in which continuous-chest–compression BLS was compared with standard BLS, in which we took 16 seconds to deliver the 2 breaths before each set of 15 compressions (Figure 6).[35] As recommended, each breath was delivered over an ≈2-second interval. After 3 minutes of untreated ventricular fibrillation, 12 minutes of BLS was initiated. Defibrillation was attempted at 15 minutes of cardiac arrest. Neurologically normal 24-hour survival was dramatically better with continuous-chest–compression CPR (CCC-CPR) versus BLS CPR the way it is actually done by lay individuals, that is, when 16 seconds is needed to deliver 2 rescue breaths before each set of 15 chest compressions. Continuous-chest–compression survival was 12 (80%) of 15 versus 2 (13%) of 15 for standard CPR.[35] In Figure 7, survival with CCC-CPR is shown as 73% rather than 80% because 73% is the average survival of the CCC-CPR groups in our 6 previously published studies involving 169 animal studies. The survival rate of 13% in our experimental model of out-of-hospital cardiac arrest was of intense interest because in Tucson, the average survival for individuals with out-of-hospital cardiac arrest due to ventricular fibrillation over the past decade was ≈13%.[22]

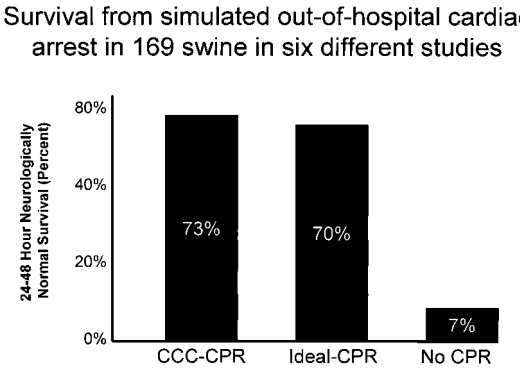

Figure 5. Survival from simulated out-of-hospital cardiac arrest due to ventricular fibrillation during single lay rescuer scenario. Results from 6 different studies are summarized (see text). Survival was the same with chest-compression-only CPR (CCC-CPR) and so-called ideal standard CPR, in which 2 breaths were delivered in 4 seconds (Ideal-CPR), and either was dramatically better than when no bystander CPR was initiated.

We wondered whether a younger population of highly motivated individuals, eg, our medical students, could deliver the recommend 2 breaths any faster. In a study using manikins, we found that it took medical students an average of 14±1 seconds to perform the 2 recommended breaths for rescue breathing.[43] We then recorded paramedics' performance and found that it took them an average of 10±1 seconds.[44] Thus, it takes a considerable amount of time for the 2 respirations that are to be given before each set of 15 chest compressions. This markedly limits the number of chest compressions being delivered.

Experimental and human data support the need for >80 compressions per minute to achieve optimal blood flow during CPR.[45–47] In addition, our studies have shown that compression rates of 100 to 120 per minute are better than 80 per minute and that the use of a metronome to ensure an appropriate chest compression rate improves perfusion in humans.[46,47] The guidelines for adult BLS were changed in the mid 1990s and recommended that a single rescuer deliver 2 ventilations before each set of 15 chest compressions. The revised recommended compression rate of 100 per minute was intended to increase the total number of delivered compressions to 64 per minute, with the assumption that the pause for the 2 ventilations takes 4 seconds[2]; however, as noted above, this appears to be physically impossible.

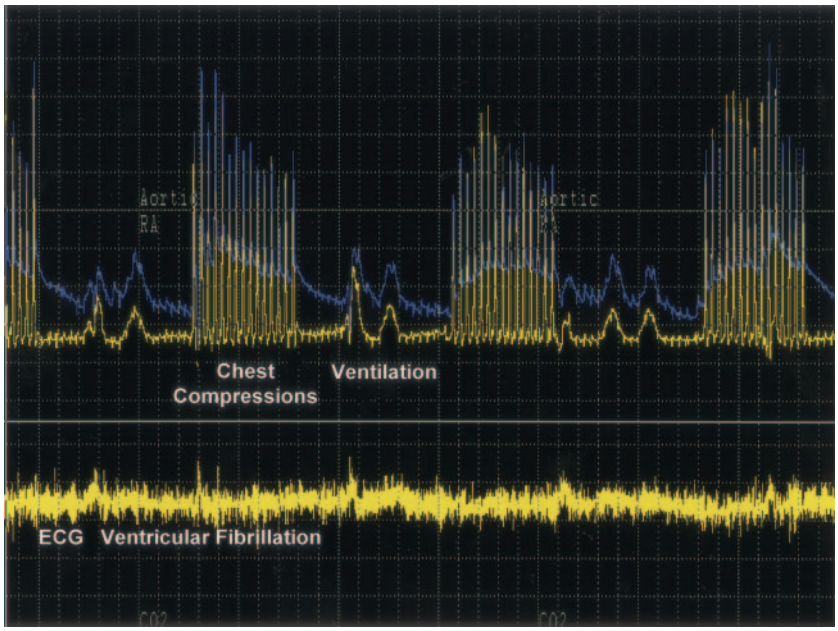

Figure 6. Simultaneous recording of aortic (blue) and right atrial (yellow) pressures during simulated single lay rescuer scenario in which each 2 ventilations are delivered within 16 seconds. ECG (bottom yellow) shows continuous ventricular fibrillation. Note that 15 chest compressions take less time than 2 ventilations (see text).

Another observation is that if a subject collapses with ventricular fibrillation, gasping lasts from 2 to 4 minutes. Gasping is both fortunate and unfortunate. It is fortunate because when chest compression is initiated promptly, the subject is likely to continue to gasp and provide self-ventilation. In fact, Kouwenhoven et al, in one of their early programs, indicated that ventilation was not necessary during chest compression as the subject gasped (W.B. Kouwenhoven, J.R. Jude, and G.B. Knickerbocker, demonstration of the technique of CPR for New York Society of Anesthesiologist 1960s; copy of demonstration provided on CD by J.R. Jude). However, gasping may be unfortunate, because most lay individuals interpret this as an indication that the individual is still breathing and do not initiate bystander CPR or call 9-1-1 as soon as they should. Our survey indicated that chest-compression–only CPR, or CCC-CPR, is more likely to be initiated by bystanders, and our research demonstrates that during the first 15 minutes of cardiac arrest due to ventricular fibrillation, CCC-CPR is dramatically better than standard CPR, because ventilation takes so long that the chest is being compressed less than half of the time.[27,35]

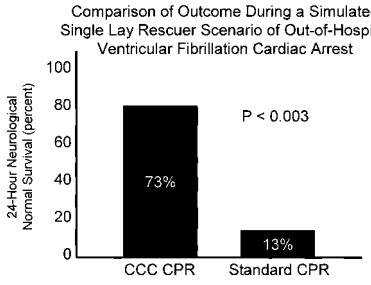

Figure 7. Comparison of 24-hour neurologically normal survival (percent) during simulated single lay rescuer scenario of out-of-hospital ventricular fibrillation cardiac arrest. CCC-CPR is continuous-chest-compression CPR without ventilation; Standard CPR is when each set of 15 chest compressions was interrupted for 16 seconds to deliver 2 ventilations.

On the basis of the above data, one aspect of our Sarver Heart Center/Tucson Fire Department Initiative for Excellence in CPR is our "Be A Lifesaver" program for the public.[22] This program encourages citizens to call 9-1-1 and then initiate continuous chest compression without mouth-to-mouth ventilation for out-of-hospital witnessed unexpected sudden collapse in adults until the paramedics/firefighters arrive. The purpose of this initiative is to dramatically increase the incidence of bystander- or citizen-initiated CPR.

The 3 steps of our Be A Lifesaver program are presented in the Table. Another major advantage of this program is that individuals can be taught CCC-CPR in a relatively short period of time. A demonstration can be seen by accessing the Sarver Heart Center World Wide Web site at www.arizona.heart.edu. Our Be A Lifesaver program also recognizes the importance of the use of AEDs early in witnessed unexpected sudden collapse in adults (Table).

It is of historical interest that physicians in the Netherlands were the first to recognize that if an adult develops ventricular fibrillation and suddenly collapses, his or her lungs, pulmonary veins, left heart, aorta, and all of the arteries are full of oxygenated blood.[48] They suggested that the mnemonic for cardiac arrest should not be ABC, for airway, breathing, and circulation, but CBA, for chest compression first, breathing, and then attention to airway if there was a problem with breathing.[48]

Our recommendations are for witnessed unexpected sudden collapse in an adult, a condition that is almost always due to cardiac arrest. In contrast, in patients with respiratory arrest, ventilation is critically important. Chest compressions plus mouth-to-mouth rescue breathing is markedly superior to either technique alone.[48] Nevertheless, studies of asphyxial cardiac arrest in swine have shown that chest compression is better, but only slightly better, than doing nothing.[49]

CCC-CPR Supported by Observations in Humans

Since our Tucson program was initiated, physicians from Tokyo, Japan, reported on their observational study of 7138

Be a Lifesaver With Continuous-Chest-Compression CPR

In witnessed sudden cardiac arrest in adults, mouth-to-mouth resuscitation is not necessary.* Follow these instructions to perform continuous-chest-compression CPR:

1. Direct someone to call 9-1-1 or make the call yourself.
2. Position the victim on his or her back on the floor. Place one of your hands on top of the other and place the heel of the bottom hand on the center of the victim's chest. Lock your elbows and begin forceful chest compressions at a rate of 100 per minute.
3. If an automated external defibrillator (AED) is available, attach it to the victim and follow the machine's instructions. If no AED is available, perform continuous chest compressions until paramedics arrive. Take turns if you have a partner.

*In cases involving children, suspected drowning, or suspected drug overdose, follow standard American Heart Association CPR procedures.

patients with out-of-hospital cardiac arrest.[50] They found that chest-compression–only CPR was the best independent predictor of their primary end point of neurologically normal hospital discharge, with an adjusted OR of 2.5 ($P=0.002$).[50]

Dispatch-Directed CCC-CPR

After "Guidelines 2000" were published, Hallstrom and associates[51] from Seattle, Wash, published a 6-year study involving 520 patients who were randomized to telephone dispatch–directed standard CPR or CPR with chest compression but without mouth-to-mouth resuscitation. They found that survival was 10.4% with standard CPR and 14.6% with chest-compression–only CPR.[51] Accordingly, as part of our overall program, the first change in the Tucson Fire Department Emergency Medical Service system was to have telephone dispatchers provide instructions for chest-compression–only CPR.

Present Guidelines for Paramedics Are Also Not Optimal

The Ontario Prehospital Advanced Life Support (OPALS) study tested the incremental effect on survival after out-of-hospital cardiac arrest of the addition of a program of advanced life support to a program of bystander BLS and encouraged use of AEDs.[26] They found that the addition of advanced life support intervention, as currently practiced, did not improve the rate of survival after out-of-hospital cardiac arrest in a previously optimized emergency medical service system of rapid defibrillation.[26] Does this mean we can do away with our expensive paramedic systems, or does this mean that the present approach and guidelines for the paramedics are also not optimal? We think the "Guidelines 2000" for the paramedics are also not optimal.

Chest Compressions Are Necessary Before Defibrillation During the Hemodynamic Phase of Cardiac Arrest

Cobb and associates[52] noted that as more of their paramedic/firefighter units were supplied with AEDs, the survival rate appeared to decline. Therefore, they changed their protocol so that the units performed 90 seconds of chest compression before applying the AED. They found that when this was done, survival improved.[52] This information was known at the time of the writing of "Guidelines 2000," but because this change in the Seattle protocols was made while another study was being done, this finding was not incorporated into the guidelines. Professor L. Wik, from Oslo, Norway, noted this controversy and studied this question.[53] In a randomized trial of 200 patients with out-of-hospital cardiac arrest, paramedics performed either 3 minutes of chest compression before defibrillation or defibrillated first.[53] They found that when the ambulance arrived in fewer than 5 minutes (during the electrical phase of cardiac arrest), there was no difference in outcome; however, when the ambulance arrived after 5 minutes (during the hemodynamic phase of cardiac arrest), there was a dramatic difference. In this group, the 1-year survival rate was 4% in the shock-first group and 20% in the chest-compression–first group.[53] A detailed analysis of the Seattle data revealed similar results.[53] In the group who were attended to within 4 minutes, there was no difference in survival to hospital discharge (31% for chest compression first and 32% for defibrillation first); however, in patients treated after 4 minutes, survival was greater (27%) in the group with 90 seconds of chest compression first than in the group who received AED shock first (17% survival).[54]

In Tucson, the average arrival time of paramedic/firefighters is ≈7 minutes, that is, in the hemodynamic phase of cardiac arrest. Accordingly, Tucson paramedic/firefighters have been instructed to give 200 chest compressions before defibrillation. We decided on 200 compressions at 100 compressions per minute because it was between the 90 seconds in the study by Cobb et al[52] and the 3 minutes used by Wik et al.[53] Two hundred chest compressions should take ≈2 minutes to perform and do not require the paramedics/firefighters to time the duration of the chest compressions, only to count them.

Limiting Interruptions of Chest Compressions by Paramedics/Firefighters

Associates from our CPR research group have documented that paramedics/firefighters are compressing the chest of the victim less than half of the time they are at the scene (Terry Valenzuela, MD, written communication, December 14, 2004). This lack of compressions appeared to be the result of the paramedics following guidelines and using AEDs. This was an astounding finding. Accordingly, the first change that was made in our paramedic program was to ensure that 1 paramedic/firefighter is compressing the chest continuously, with only short interruptions for defibrillation shock and rhythm analysis. Intubation is delayed until 3 series of 200 chest compressions, shock, 200 postshock chest compressions, and rhythm analysis are performed. Emphasis is placed on obtaining intravenous access. Intubation is delayed until after 3 series of compressions and defibrillations.

Support for delaying intubation and using a bag-valve-mask for ventilation is supported by the study of Gausche and associates.[54] Their controlled clinical trial of patients aged 12 years and younger or weighing an estimated 40 kg or less

showed no significant difference in survival between the bag-valve-mask group (30%) and the endotracheal intubation group (26%).[54] This important finding (that endotracheal intubation was not superior to bag-valve-mask ventilation even in the pediatric age group, a group in whom respiratory arrest is expected to be more common) supports the fact that endotracheal intubation, although commonly performed and commonly thought to be of the highest priority, is not critically important and is probably deleterious because it results in interruptions of chest compression.

Avoiding the Immediate Deployment of AEDs During the Hemodynamic Phase of Cardiac Arrest

Most AEDs available during and before 2003 took a significant amount of time to analyze the patient's rhythm, to recommend defibrillation shock, and then to analyze the postshock rhythm, such that minutes were added to the arrest time, which makes resuscitation less likely.[55,56] Accordingly, the immediate deployment of an AED by paramedics/firefighters arriving during the hemodynamic phase of cardiac arrest may decrease the chances of survival from out-of-hospital cardiac arrest.[56,57] These devices result in prolonged interruption of precordial compression during the hemodynamic phase of cardiac arrest and contribute to poor survival.[57] The Tucson paramedics/firefighters are instructed to use the "quick look" features of defibrillators if available.

Two Hundred Chest Compressions by Paramedics/Firefighters After Shock and Before Rhythm Analysis

As noted above, paramedics/firefighters are instructed to perform another 200 chest compressions after the shock before assessing the rhythm. This is based on the fact that after prolonged ventricular fibrillation, the shock frequently defibrillates, but to a nonperfusing rhythm. In fact, to produce pulseless electrical activity (PEA) in the experimental laboratory, one fibrillates the animal, does no chest compression for several minutes, then defibrillates, and the result is usually PEA, or the older term, "electrical mechanical dissociation" or "EMD."[58,59] If chest compression is applied and the heart is perfused after the defibrillating shock, the PEA is more likely to revert to a perfusing rhythm.[59]

If the paramedics/firefighters witness the arrest, they defibrillate first. Otherwise, they assume that the patient is in the hemodynamic phase of cardiac arrest and perform 200 chest compressions, deliver the shock, and immediately perform another 200 chest compressions before rhythm analysis. As noted above, this sequence is followed 3 times before an attempt to intubate. Before intubation, the patient is ventilated via bag-valve-mask.

Excessive Ventilation Avoided

Some time after advocating chest-compression-only CPR, we changed the designation to "continuous-chest-compression CPR." Our original thought was "ventilate all you want, just do not stop pressing on the chest." We now know that "ventilate all you want" is wrong as well. Excessive ventilation is a major problem in CPR, decreasing the chances of survival.[21]

After the recommended chest compression rate was increased from 60 compressions per minute to 80 to 100 compressions per minute, we had our CPR research nurse attend a number of cardiac arrests in the hospital to count the number of chest compressions per minute that physicians were providing. The nurse also counted the number of ventilations per minute.[60] The number of ventilations was consistently more than the recommended 12 to 15 per minute.[2] Some were ventilated at a faster rate than the chest was being compressed! The average number of ventilations was 37 per minute.[60] This number became of increased interest when Aufderheide and associates[23] recently reported the same average number of excessive number of ventilations by paramedics. They then studied the effect of ventilation rate on survival in a swine model of cardiac arrest and found that excessive ventilations decreased survival.[23] With simultaneous chest compressions and ventilations, there is a dramatic increase in intrathoracic pressure, decreasing venous return, and thus perfusion pressures. The study by Aufderheide and associates[23] indicates that 12 to 15 ventilations per minute are much better than the near 30 ventilations per minute that are often delivered.

There is a need for more research into the best way for ventilation to be delivered in the various phases of cardiac arrest, depending on whether rescue breathing was performed or not. The amount and type of ventilation studied by different groups are variable, and the results have been conflicting.[61,62] Is there a role for negative pressure during ventilation, as proposed and studied by Lurie and associates[22,61]? Wik and associates[53] found that optimal paramedic ventilation is 10 mL/kg at a frequency of 12 ventilations per minute. Is this what one should recommend? This is another area that needs more study.

Just as multicenter clinical trials are necessary to provide large enough numbers from a variety of locations to ensure their validity, we think there is a need for multicenter laboratory research using common protocols to give better direction and preliminary preclinical data to support the pursuit of expensive multicenter clinical trials. Standards and guidelines for CPR have been advocated for more than 40 years, and we still only have some of the answers.

The Metabolic Phase: Hypothermia

It has long been appreciated that survival from drowning is more likely with cold water rather than warm. Although improved neurological recovery was reported by Benson et al[63] in 1959 in a small number of comatose patients after resuscitation from cardiac arrest treated with hypothermia, it was not until the simultaneous reports from Austria and Australia of improved survival and neurological outcome that this concept was more generally accepted.[64,65]

After the publication of these studies, the International Liaison Committee on Resuscitation (ILCOR) issued a new statement on hypothermia.[66] It states, "Unconscious adults with spontaneous out-of-hospital cardiac arrest and an initial rhythm of ventricular fibrillation should be cooled to 32 to 34 degrees centigrade for 12 to 24 hours."[66] They added that, "Such cooling also may be beneficial for other rhythms or for in-hospital cardiac arrest."[66] More research is needed to define the best and safest methods for postresuscitation hypothermia.

Conclusions

This article reviewed the studies that led us to institute a new system of CPR for out-of-hospital witnessed arrest due to ventricular fibrillation in adults.[3] It is called cardiocerebral resuscitation (CCR), or continuous-chest–compression CPR (CCC-CPR) for witnessed unexpected sudden cardiac arrest in adults, to differentiate it from the presently taught CPR that may be better (but we do not think ideal) for patients with respiratory arrest. Sudden witnessed collapse in an adult is most often due to ventricular fibrillation, and the present CPR as articulated by "Guidelines 2000" results in excessive interruptions of chest compressions for other presently mandated tasks.[2] These excessive interruptions are lethal.

Some of the major unanswered questions are as follows: When is ventilation mandatory during prolonged cardiocerebral resuscitation? Ventilation is probably mandatory after ≈15 minutes of chest compression only in patients who are not gasping. This needs to be studied.

If one is willing to do mouth-to-mouth rescue breathing for witnessed cardiac arrest, what is the best compression-to-ventilation ratio? One of our studies suggests that it might be continuous chest compressions for the first 4 minutes, follow by 1 or 2 ventilations before each set of 100 compressions.[67]

If bystanders perform chest-compression–only CPR and the paramedics arrive within 8 to 15 minutes, what is the best sequence of ventilation for the paramedics/firefighters? Clearly, excessive ventilation is to be avoided, but are the recommended 12 to 15 ventilations per minute optimal? Should fewer ventilations and the use of the impedance valve mask be used? Continued research in cardiocerebral resuscitation is clearly needed, but we cannot wait for all the answers, nor until the next guidelines are published, to make some needed changes.

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