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

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Overview
More people can survive sudden cardiac arrest when a particular sequence of events occurs as rapidly as possible. This sequence is 1) recognition of early warning signs, 2) activation of the emergency medical system, 3) basic cardiopulmonary resuscitation, 4) defibrillation, 5) intubation, and 6) intravenous administration of medications. The descriptive device "chain of survival" communicates this understanding in a useful way (Figure 1). While separate specialized programs are necessary to develop strength in each link, all of the links must be connected. Weakness in any link lessens the chance of survival and condemns the efforts of an emergency medical services (EMS) system to poor results. The chain of survival concept has evolved through several decades of research into sudden cardiac arrest. Effective system interventions have been identified that will allow survivors to remain neurologically intact. While a few urban systems may have approached the current practical limit for survivability from sudden cardiac arrest, most EMS systems, both in the United States and other countries, have defects in their chain. Poor resuscitation rates have been the rule. This statement describes the research supporting each link and recommends specific actions to strengthen the chain of survival.

The Links in the Chain of Survival

The Early Access Link

The chain of survival begins with early access, in which the patient is helped as quickly as possible. Early access includes the implied component of early recognition. The resuscitation chain is initiated when a medical emergency is recognized and the emergency medical system accessed and activated. The time required for access begins the moment an emergency is recognized, by either the person with symptoms or a witness to the emergency. With sudden cardiac arrest, access time begins at the moment of collapse and includes recognition of the emergency, the decision to make the call, time spent locating a telephone and emergency number, interrogation of the caller by the emergency dispatcher, and the decision to send an emergency vehicle. The dispatcher may need additional time to route the call to the proper response station or vehicle (call-processing time). Once the responder is notified, ambulance response time begins. Ambulance response time is the interval from receipt of the call by the emergency responder to...
arrival of emergency personnel at the scene. Additional time may elapse before the responder actually examines the patient. Recognition, call processing, and ambulance response time add seconds, typically minutes, to the critical interval between arrest and initiation of emergency treatment.

The most common approach to shorten the interval between collapse and arrival of emergency personnel has been to acquire more ambulances,\textsuperscript{2,3} which is both expensive and inefficient, especially if the EMS system is established. Studies have shown that after a certain point an increase in the number of ambulances fails to lower response time significantly.\textsuperscript{4} In one model, response time varied inversely as the square root of the number of vehicles per square mile; an 80% increase in the number of vehicles reduced average response time by only 1 minute.\textsuperscript{4} This same 1-minute reduction in average response time could be achieved by greater public awareness and more efficient dispatching systems, and at far less cost.

The early access link can be strengthened through public education, especially persons most likely to witness a cardiac arrest, and by installation of an efficient emergency communication system. Educational and public service programs such as those of the American Heart Association\textsuperscript{1} and the American Red Cross\textsuperscript{5} are designed to make the public aware of what to do when cardiac arrest occurs. Participants in classes on cardiopulmonary resuscitation (CPR) and AHA-sponsored schoolsite and worksite training learn the warning signs of heart attack, how to recognize a person in cardiac arrest, and to quickly call the EMS system when a person collapses.\textsuperscript{7} Such educational campaigns may become more widespread. Early access ensures that precious minutes are not wasted at the start of cardiac arrest.

Lack of a three-digit 911 emergency dispatch system (or its equivalent) can produce confusion and delays because witnesses may call the wrong number, call multiple numbers, or spend time searching for the number. In one community in North Carolina, 85 different emergency numbers are listed in the local telephone book.\textsuperscript{8,9} In contrast, in Seattle, Washington, which has an enhanced 911 system, 90% of 1,271 people interviewed identified 911 as their EMS notification number.\textsuperscript{10} Investigators from Minneapolis who performed a before-and-after evaluation of a 911 system\textsuperscript{11} noted that the percentage of emergency callers who could activate the EMS system in less than a minute rose from 63% before implementation of the system to 82% afterward. The percentage of callers who made only one telephone call to activate the system went from 40% before the 911 system was started to 74% after the system began.

Another study showed that imprecise knowledge of how to notify the emergency system can cause confusion and delays.\textsuperscript{12} In this telephone survey, people living in 911 system communities knew the correct number to call 85% of the time; in regional systems with several fire departments operating from one dispatching center, people knew the correct number to call only 47% of the time; in systems with a local seven-digit number for a particular fire district, people gave the correct number only 36% of the time. Many people who lived near a 911 area thought 911 was their emergency number; when they mistakenly called 911, delays of 30 seconds to 2 minutes resulted. Establishment of a 911 emergency system is a key step. Given the transient and mobile nature of today’s population, a universal access number must be adopted by EMS systems. By 1992 a common emergency telephone number will be introduced in the European community and will cover a population of more than 350 million.

The Early CPR Link

The next link in the chain of survival is early initiation of basic CPR.\textsuperscript{1,13} Basic CPR should be started immediately after cardiac arrest is recognized and should coincide with efforts to gain access to and activate the EMS system. EMS systems should rely on trained citizens rather than emergency responders to initiate CPR. With rare exceptions, initiation of CPR by emergency personnel is too late. Only systems with rapid response times, such as that in Milwaukee, Wisconsin,\textsuperscript{14,15} can employ EMS providers as the primary initiators of CPR.

For almost 3 decades the chest compressions and positive pressure ventilations of standard CPR have helped return pulseless, nonbreathing patients to spontaneous respiration and cardiac perfusion.\textsuperscript{16,17} The value of early CPR is that it can buy time for the primary cardiac arrest patient\textsuperscript{1,13,18–22} by producing
enough blood flow to the central nervous system and the myocardium to maintain temporary viability. To do so, however, basic CPR must be started early, and the earlier the better. Initial CPR must be followed by rapid defibrillation, intubation, and administration of cardiovascular medications by EMS personnel. Early bystander CPR is less helpful in resuscitation if EMS personnel equipped with the defibrillator arrive late, or about 8–12 minutes after collapse. Recent data from the Belgium Cardio-Pulmonary-Cerebral Resuscitation Registry and Scotland, however, suggest some prolonged benefit from bystander CPR even with late arrival of advanced life support personnel. The combination of late CPR (more than 4 minutes) and late advanced life support (more than 12 minutes) is particularly lethal. Several researchers have called these time dimensions the resuscitation “failure zone.”

Many reports contain data to compare the survival rates of cardiac arrest victims who receive early CPR (defined as citizen-initiated CPR) with the survival rates of those who receive late CPR (defined as emergency responder–initiated CPR). Table 1 presents summary data from these studies, including estimated odds ratios for survival. Early CPR usually differs from late CPR by about 4 minutes. In all but one system, researchers observed a positive benefit of early CPR when they compared survival rates between persons who received early CPR and those who received late CPR. The magnitude of this contribution may be considerable since the odds ratios for improved survival with early CPR can range as high as 11.5 (Table 1). In Milwaukee, the only system in which this benefit was not observed, emergency personnel performed late CPR an average interval of only 2 minutes after early bystander-initiated CPR. Thus the data from Milwaukee simply compare early CPR with even earlier CPR. The similar survival rates for people who received bystander CPR compared with those deprived of bystander CPR are not surprising and provide additional support for the concept of a narrow window of CPR effectiveness. The association between early CPR and improved survival appears related to the effect of basic CPR on ventricular fibrillation. Researchers have observed that when rescuers start CPR early, the patient is more likely to be in ventricular fibrillation when a monitoring unit arrives. Investigators in King County, Washington, observed that 80% of cardiac arrest victims were in ventricular fibrillation/ventricular tachycardia if they had received early bystander CPR, compared with 68% if they had received delayed CPR. In Stockholm, 67% of people in cardiac arrest in whom CPR was started by bystanders were in ventricular fibrillation/ventricular tachycardia, whereas only 45% of persons not given bystander CPR were in ventricular fibrillation/ventricular tachycardia. The Belgian Cardio-Pulmonary-Cerebral Resuscitation Registry has reported a 42% prevalence of ventricular fibrillation in cardiac arrest patients who received bystander CPR, compared with 29% in arrest patients who received delayed CPR.

These three studies suggest that CPR prolongs the duration of ventricular fibrillation. In addition, they suggest that the presence of ventricular fibrillation operates as a dependent variable rather than an independent variable in analyses of survival data. Victims who receive early CPR are also more likely after electrical shock to convert to a cardiac rhythm associated with restoration of spontaneous circulation. In King County, Washington, persons in ventricular fibrillation when EMS personnel arrived had a 37% rate of long-term survival if they were given bystander CPR, compared with 29% if they were not. In Houston, 40% of patients with ventricular fibrillation/ventricular tachycardia were discharged from the hospital if they had received bystander CPR, versus 19% for such patients not given bystander CPR.

Several approaches ensure the performance of basic CPR by bystanders before emergency responders arrive. The most widely advocated is citizen CPR training. Community-based CPR training programs, endorsed and conducted by the American Heart Association and the American Red Cross, have trained millions of laypersons in CPR. The American Heart Association has suggested that if 20% of adults were trained in CPR, morbidity and mortality from out-of-hospital cardiac arrest might be significantly reduced. Some communities have actually achieved this level of adult training, despite physician reluctance to “prescribe” CPR training for family members and friends of high-risk patients. In the Seattle area, for example, Leonard Cobb and coworkers have trained over 2 million people. In Minneapolis a survey of 2,310 adults noted that 23% were trained in CPR.

However, there are problems with the concept that a threshold level of citizen training can be “protective.” Most people trained in CPR never see an arrest; most people who see an arrest have not been trained in CPR. The Minneapolis survey found that only 10% of the population trained in CPR had witnessed a cardiac arrest and only 30% of witnesses to a cardiac arrest had been trained in CPR. Only 19% of persons trained in Minneapolis continued retraining every year. This figure nearly duplicates that in a report by Gombeski, who noted that only 21% of their trainees returned for 1-year retraining.

Other data, however, suggest a more positive picture. Eisenberg et al observed that some knowledge of CPR techniques is so prevalent that many citizens attempt CPR without formal training. In addition, they perform CPR despite a high prevalence of disagreeable physical characteristics (the presence of saliva, blood, or emesis) encountered during performance of bystander CPR. Cobb et al observed that outcomes for CPR by untrained citizens is similar to outcomes for trained laypersons. The Belgian Cardio-Pulmonary-Cerebral Resuscita-
TABLE 1. Controlled Studies of Survival (Discharged Alive) From Out-of-Hospital Cardiac Arrest: Bystander Cardiopulmonary Resuscitation Compared With Late Cardiopulmonary Resuscitation

<table>
<thead>
<tr>
<th>Location/system</th>
<th>Witnessed arrest</th>
<th>Rhythm</th>
<th>Number of patients</th>
<th>Discharged alive (n)</th>
<th>Odds ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oslo, Norway28</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Bys CPR=75</td>
<td>36% (27)</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late CPR=556</td>
<td>8% (43)</td>
<td></td>
</tr>
<tr>
<td>2. Birmingham39</td>
<td>Implied yes</td>
<td>VF or VT</td>
<td>Bys CPR=7</td>
<td>86% (6)</td>
<td>6.0</td>
</tr>
<tr>
<td>Paramedics only</td>
<td></td>
<td></td>
<td>Late CPR=12</td>
<td>50% (6)</td>
<td></td>
</tr>
<tr>
<td>3. Seattle30</td>
<td>76% overall witnessed</td>
<td>VF only</td>
<td>Bys CPR=109</td>
<td>43% (47)</td>
<td>2.9</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=207</td>
<td>21% (43)</td>
<td></td>
</tr>
<tr>
<td>4. Winnipeg31</td>
<td>Not reported</td>
<td>VF or VT</td>
<td>Bys CPR=65</td>
<td>25% (16)</td>
<td>6.2</td>
</tr>
<tr>
<td>EMTs only</td>
<td></td>
<td></td>
<td>Late CPR=161</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Iceland32</td>
<td>Not reported</td>
<td>All rhythms</td>
<td>Bys CPR=38</td>
<td>42% (16)</td>
<td>11.5</td>
</tr>
<tr>
<td>EMTs only</td>
<td></td>
<td></td>
<td>Late CPR=84</td>
<td>2% (2)</td>
<td></td>
</tr>
<tr>
<td>6. Vancouver33</td>
<td>77% overall witnessed</td>
<td>All rhythms</td>
<td>Bys CPR=43</td>
<td>21% (9)</td>
<td>4.0</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=272</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Los Angeles34</td>
<td>41% overall witnessed</td>
<td>All rhythms</td>
<td>Bys CPR=93</td>
<td>22% (20)</td>
<td>5.6</td>
</tr>
<tr>
<td>Paramedics</td>
<td></td>
<td></td>
<td>Late CPR=150</td>
<td>5% (7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VF only</td>
<td>Bys CPR=45</td>
<td>27% (12)</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late CPR=70</td>
<td>6% (4)</td>
<td></td>
</tr>
<tr>
<td>8. King County13</td>
<td>Not reported</td>
<td>All rhythms</td>
<td>Bys CPR=108</td>
<td>23% (25)</td>
<td>2.2</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=379</td>
<td>2% (45)</td>
<td></td>
</tr>
<tr>
<td>9. Pittsburgh35</td>
<td>Not reported</td>
<td>VF/VT only</td>
<td>Bys CPR=25</td>
<td>24% (6)</td>
<td>4.3</td>
</tr>
<tr>
<td>Paramedics</td>
<td></td>
<td></td>
<td>Late CPR=59</td>
<td>7% (4)</td>
<td></td>
</tr>
<tr>
<td>10. Milwaukee36</td>
<td>Witnessed only</td>
<td>All rhythms</td>
<td>Bys CPR=1,248</td>
<td>15% (182)</td>
<td>1.0</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Coarse VF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bys CPR=252</td>
<td>15% (38)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late CPR=628</td>
<td>24% (148)</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late CPR=151</td>
<td>23% (35)</td>
<td></td>
</tr>
<tr>
<td>11. Michigan/Ohio37</td>
<td>Not reported</td>
<td>All rhythms</td>
<td>Bys CPR=472</td>
<td>13% (56)</td>
<td>2.7</td>
</tr>
<tr>
<td>communities (EMTs and paramedics)</td>
<td></td>
<td></td>
<td>Late CPR=1,367</td>
<td>5% (64)</td>
<td></td>
</tr>
<tr>
<td>12. King County38</td>
<td>Both</td>
<td>All rhythms</td>
<td>Bys CPR=726</td>
<td>27% (196)</td>
<td>2.4</td>
</tr>
<tr>
<td>EMT-Ds and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=1,317</td>
<td>13% (177)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Witnessed only</td>
<td>All rhythms</td>
<td>Bys CPR=579</td>
<td>32% (186)</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late CPR=718</td>
<td>22% (158)</td>
<td></td>
</tr>
<tr>
<td>13. York/Adams, Pa.39</td>
<td>Witnessed only</td>
<td>VF only</td>
<td>Bys CPR=157</td>
<td>22% (34)</td>
<td>4.5</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=225</td>
<td>6% (13)</td>
<td></td>
</tr>
<tr>
<td>14. Tucson, Ariz.40</td>
<td>Witnessed only</td>
<td>All rhythms</td>
<td>Bys CPR=65</td>
<td>20% (13)</td>
<td>2.5</td>
</tr>
<tr>
<td>EMTs and paramedics</td>
<td></td>
<td></td>
<td>Late CPR=130</td>
<td>9% (12)</td>
<td></td>
</tr>
<tr>
<td>15. West Yorkshire42</td>
<td>Not reported</td>
<td>All rhythms</td>
<td>Bys CPR=47</td>
<td>15% (7)</td>
<td>2.0</td>
</tr>
<tr>
<td>Ambulance personnel</td>
<td></td>
<td></td>
<td>Late CPR=50</td>
<td>8% (4)</td>
<td></td>
</tr>
<tr>
<td>16. Belgium41</td>
<td>Not reported</td>
<td>All rhythms</td>
<td>Bys CPR=985</td>
<td>10% (98)</td>
<td>1.9</td>
</tr>
<tr>
<td>Ambulance Personnel</td>
<td></td>
<td></td>
<td>Late CPR=2,036</td>
<td>5% (109)</td>
<td></td>
</tr>
<tr>
<td>17. Houston22</td>
<td>Both</td>
<td>Unmonitored VF/VT</td>
<td>Bys CPR=53</td>
<td>30% (16)</td>
<td>2.1</td>
</tr>
<tr>
<td>EMTs and medics</td>
<td></td>
<td></td>
<td>Late CPR=133</td>
<td>14% (19)</td>
<td></td>
</tr>
</tbody>
</table>

EMT, emergency medical technician; EMT-D, emergency medical technician trained to defibrillate; VF, ventricular fibrillation; VT, ventricular tachycardia; Bys, bystander; CPR, cardiopulmonary resuscitation.

*Odds ratio is not a simple ratio of survival rates. It is calculated as the odds of surviving with bystander CPR (number discharged alive divided by number who die) divided by the odds of discharge alive for people who received late CPR (number discharged alive divided by number who die).

tion Registry has noted that the quality of bystander CPR is difficult to evaluate.55 In Belgium the most common bystander CPR errors were omission of mouth-to-mouth ventilations, which occurred 46% of the time, and omission of chest compressions, which occurred 17% of the time.55 Outcomes were significantly better when rescuers performed both ventilations and chest compressions, compared with ventilations alone or compressions alone.55

Another approach to early CPR is the concept of targeted CPR training.10,53,54,56–59 Such programs are for persons who have an increased likelihood of having to perform CPR, including middle-aged persons, residents and staff of senior centers, survivors of
myocardial infarction, and family members of persons identified as having cardiac arrest risk factors. These programs are slowly becoming more widespread and represent an important change in the focus of CPR training. Much CPR training in the United States focuses on the young, especially school-age children and young adults, by easy to train and show energetic interest. However, they are not likely to witness a cardiac arrest or to take a CPR course. They do, of course, become the “future” performers of CPR as they enter the age group where risk increases. Cardiac arrest victims are typically aging men, who live at home, and are usually poorly educated and nonprofessional. In King County, Washington, the average age of cardiac arrest patients is 65 years; 77% of cardiac arrests happen at home, and 75% of the victims are men. Therefore, persons with the highest likelihood of witnessing a cardiac arrest and being called upon to perform CPR are those living with or closely associated with middle-aged men. Regardless of age, the prognosis for persons resuscitated from cardiac arrest, even the elderly (those over 70 years old), is excellent. Unfortunately, few middle-aged women in the United States have received formal CPR training, and those who have received training seldom live with high-risk patients. In one survey of people trained to perform CPR, only 7% lived with family members known to have heart disease.

A final method to achieve early CPR is dispatcher-assisted CPR instruction, programs in which emergency telephone dispatchers offer CPR instructions to persons who call to report a cardiac arrest. Delivery of instructions and performance of a complete CPR cycle of 15 chest compressions and 2 ventilations can be accomplished in 3–4 minutes, even by persons who have never received CPR training. Telephone instruction also improves the quality of CPR performed by persons with prior CPR training in manikin simulations. Panicked bystanders can be calmed and directed by dispatchers and encouraged to perform CPR, despite their alarm at the sudden sight of a loved one who is cyanotic and breathless. With this program, plus other educational efforts, the percent of cardiac arrests in which CPR was initiated by bystanders in King County, Washington, has increased from 30% in 1980 to 60% in 1988 (unpublished data).

The Early Defibrillation Link

The purpose of early defibrillation is to reestablish a normal spontaneous rhythm in the heart. Several new approaches can help achieve early defibrillation:

- Automated defibrillators used by the first responding emergency personnel
- Automated defibrillators used by community responders, that is, persons whose usual occupation or training does not require responding to emergencies
- Home defibrillation programs for high-risk patients
- Transtelephonic defibrillation

The rationale for early defibrillation emerges from data that demonstrate that almost 85% of persons with ambulatory, out-of-hospital, primary cardiac arrest experience ventricular tachyarrhythmias during the early minutes after collapse. In one report 157 ambulatory (not hospitalized) patients experienced fatal arrhythmias during continuous cardiac monitoring. The initial dysrhythmia in 62% of patients was ventricular tachycardia that quickly evolved to ventricular fibrillation, in 8% the dysrhythmia was primary ventricular fibrillation, and in 13% it was torsades de pointes. The duration of the ventricular tachycardia that preceded the ventricular fibrillation ranged from a few seconds to several minutes. This study involved a select population of patients who had some indication for ambulatory cardiac monitoring. Nevertheless, the rhythms they experienced are probably representative of the usual initial rhythms of the sudden cardiac arrest victim.

In prehospital studies, the rhythm of arrest cannot be identified until emergency personnel arrive with a defibrillator/monitor, 4–8 minutes later. In these studies the percent of people in ventricular tachyarrhythmias was lower, at 60% or less. Most eventual survivors emerge from the group of people who remain in ventricular fibrillation when emergency personnel arrive. For example, in King County, Washington, over 92% of cardiac arrest survivors were from this group, and over 80% in Houston.

Additional evidence about the importance of early defibrillation comes from cardiac arrest experiences in supervised cardiac rehabilitation programs. On the rare occasion when a person in such a program experiences cardiac arrest, it is witnessed, CPR is started immediately, and defibrillation is performed within minutes. Fletcher and Cantwell reported five cardiac arrests in a medically supervised exercise program; all were resuscitated. Haskell reported that among 13,570 patients in 30 exercise centers, 50 cardiac arrests occurred and 42 (84%) were resuscitated. Hossack and Hartwig observed 2,464 people in a supervised cardiac rehabilitation program over a 13-year period. In this group 25 men suffered a cardiac arrest, and all 25 (100%) were successfully resuscitated. Van Camp and Peterson summarized the experience in 167 cardiac rehabilitation programs; 21 cardiac arrests occurred, and personnel resuscitated 18 (86%) without neurologic sequelae. The type of rhythm at arrest in these series was not reported, but sudden arrest during exercise suggests that the large majority of these patients were in ventricular fibrillation. Overall, of 101 cardiac arrests in these reports, staff members resuscitated 90 (89%) of the victims. This is the highest survival rate reported among defined population groups, and it confirms the value of immediate efforts in early CPR and defibrillation.

In England, general practitioners, the most frequent responders to patients with chest pain and cardiac arrest, have observed that early defibrillation alone produces successful resuscitations. Many pa-
tients in Britain call their general practitioner during the early stages of a myocardial infarction. About 5% of these patients experience a cardiac arrest after the physician arrives.74,75 The British Heart Foundation donated 78 defibrillators to 25 general practices and reported on the experiences after 1 year.73 A total of 19 patients suffered cardiac arrest in the presence of a general practitioner who had a defibrillator: 13 (68%) were in ventricular fibrillation, nine were successfully resuscitated outside the hospital, and six were discharged from the hospital.73

In the earliest prehospital programs,33–35,42,76–86 only paramedics provided defibrillation. In most studies of paramedic-only systems, the time between collapse and arrival of paramedics averaged more than 12 minutes. These programs therefore generally provide what is more correctly termed late defibrillation. Consequently, the reported survival rates for these systems have been modest, ranging from 7% to 18% for all rhythms.87 Researchers in the early 1980s demonstrated the ability of personnel less well trained than paramedics, namely, emergency medical technicians (EMTs), to successfully use defibrillators.88–91 Early defibrillation programs implemented for firefighters and minimally trained EMS first responders spread slowly, more often because of implementation barriers and administrative inertia than from doubt of clinical efficacy.92,93

The proposals to allow less well trained emergency personnel to operate defibrillators initially provoked controversy, but most concerns have since disappeared. Conceptually, early defibrillation programs represented the transfer of what was a medical act—diagnosis of the rhythm and operation of a defibrillator—into the hands of nonphysicians. Some authorities accepted the transfer of skills to paramedics. However, many authorities hesitated to permit defibrillation by less well trained emergency personnel. Rational reasons for this hesitancy vanished by the late 1980s with widespread acceptance of the principle of early defibrillation1,20,23 and the success of automated external defibrillators.94,95 Regrettably, in Germany, France, Japan, and other countries, medicolegal factors still prevent implementation of early defibrillation programs by nonphysicians.

The principle of early defibrillation holds that the professional rescuer who arrives first at the scene of a cardiac arrest should carry a defibrillator and be trained to operate it.1,20,23 With few exceptions, the defibrillator should be automated and external.93,94,96–102 Automated external defibrillators are highly accurate98,99,101–103 and eliminate the need for training in the complex skills of rhythm recognition. The operator simply attaches the defibrillator’s adhesive electrodes to the chest of the person thought to be in cardiac arrest. When activated by a single control, the device analyzes the rhythm, and if ventricular fibrillation or tachycardia is present, the device either charges and delivers a shock (automatic devices) or indicates to the operator that a shock is needed (semiautomatic, or shock-advisory, de-

ices).104,105 With shock-advisory devices, the operator delivers the shock by pushing a second control.104,106 This simplicity of operation decreases the time and expense of initial training and continuing education and markedly increases the number of persons who can operate the devices. Clinical studies also show that systems using automated defibrillators can deliver the first shock up to 1 minute faster than conventional defibrillators because of the speed with which these devices can be attached and with which they operate.98,99

Each year more communities in the United States allow the use of both automated and conventional defibrillators by EMTs and by less trained personnel called first responders, a term that refers specifically to persons who have completed a 40-hour course. The term can refer to a much larger group of public safety employees, including firefighters, ambulance personnel, part-time emergency volunteers, police officers, highway patrol personnel, security guards, merchant marine sailors, and airline, railroad, and other public transportation vehicle crews.

Automated defibrillators are used by first responders around the world,107,108 with early defibrillation programs in Scotland,25 Denmark,109 England,6 West Berlin,107,108 Norway,110 Sweden,43 Australia,111 Singapore,112 Finland, Belgium, and many other countries. By 1988, 37 states in the United States had passed legislation permitting early defibrillation by EMTs and, in some states, basic first responders.113 An additional 10 states planned to initiate similar programs in 1989,113 Many communities permit first-responder (usually firefighter) defibrillation, including Houston; Dallas; Memphis; San Francisco; Salt Lake City; Seattle; King County, Washington; and Eugene-Springfield, Oregon.102,114–116 The International Association of Fire Chiefs has endorsed this concept and has started an initiative called RapidZap,114–116 which has the goal of equipping all fire department emergency response vehicles with automated defibrillators by the year 2000. The fire chiefs adopted this concept not only out of concern to provide effective care for all citizens but also concern for the well-being of their personnel. Surveys of firefighter deaths have noted that the majority of on-duty deaths are due to sudden cardiac arrest.117,118

How effective are programs in which defibrillators are given to EMTs and first responders? Variable degrees of success have been observed in clinical studies thus far. The published survival rates for systems whose prehospital response teams consist only of EMTs trained in defibrillation range from 6% to 26% for patients found to be in ventricular fibrillation.43,88,89,119–121 The most important comparison, however, is between the survival rate in communities before and after institution of an early defibrillation program. In suburban communities in King County, Washington, for example, the survival rate for patients in ventricular fibrillation increased from 7% to 26%.88 Similarly,
in communities in Iowa it increased from 3% to 19%. In southeastern Minnesota the survival rate was 4% without EMT defibrillation and 17% with such a program, whereas in northeastern Minnesota the survival rate was 2.5% without and 9.9% with EMT defibrillation. When an early defibrillation program was started in certain Wisconsin communities, the survival rate rose from 3.6% to 6.4% for all cardiac arrests and was 11% for patients initially noted to be in ventricular fibrillation (Table 2). It is important to note that these programs should maintain and increase initial improvements in survival rates as experience and competency improve over time.

**Home and community responder defibrillation programs.** Two other techniques advocated to help achieve early defibrillation are home defibrillation programs for high-risk patients and early defibrillation by community responders. Community responders include public safety workers or laypersons who may have a perceived duty to respond to an emergency. Although these approaches have been under evaluation for several years, their specific effects on community-wide survival rates from cardiac arrest have not been determined. Moore et al observed that of 95 survivors of ventricular fibrillation, only 63 (66%) were eligible for a home defibrillator, and only 38 of 47 (81%) persons approached agreed to participate. This suggests that approximately half of ventricular fibrillation survivors would receive the device and appropriate training. McDaniel et al also experienced recruitment problems in a similar home-defibrillation study. Only 8% of survivors of acute myocardial infarction participated in their study. The reasons for low participation included patients living alone, patients discharged to nursing homes, patients having no telephone, resuscitation considered medically inappropriate, implantation of automatic internal defibrillators, residence outside the study areas, no perceived chance of repeat cardiac arrest, religious objections, and elimination from the study at the demand of personal physicians.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before early defibrillation</th>
<th>After early defibrillation</th>
<th>Odds ratio for improved survival*</th>
</tr>
</thead>
<tbody>
<tr>
<td>King County</td>
<td>7% (4/56)</td>
<td>26% (10/38)</td>
<td>4.6</td>
</tr>
<tr>
<td>Iowa</td>
<td>3% (1/31)</td>
<td>19% (12/64)</td>
<td>6.9</td>
</tr>
<tr>
<td>Southeastern Minnesota</td>
<td>4% (1/27)</td>
<td>17% (6/36)</td>
<td>5.2</td>
</tr>
<tr>
<td>Northeastern Minnesota</td>
<td>3% (3/118)</td>
<td>10% (8/81)</td>
<td>4.2</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>4% (32/893)</td>
<td>11% (33/304)</td>
<td>3.3</td>
</tr>
</tbody>
</table>

*The odds ratio is not a simple ratio of survival rates. It is calculated as the odds of surviving after an early defibrillation program (number who live divided by number who die), divided by the odds of surviving before an early defibrillation program (number who live divided by number who die).
international air carrier. This preliminary study ceased when another company purchased the air
carrier, but senior cabin attendants trained with great
enthusiasm. Several other airlines are likely to imple-
ment similar programs in the near future. In London
researchers trained conductors to operate automated defibrillators. There
are early anecdotal reports of successful resuscita-
tions. High-risk or isolated industrial settings rep-
resent another interesting target group for imple-
mentation of early defibrillation programs. Safety
personnel have, for example, placed and successfully
used automated external defibrillators on oil plat-
forms in the North Sea, at electricity plants, and on
passenger cruise ships and merchant marine ves-
sels.

Future research will help establish the exact role of
these innovative approaches. However, clinical evi-
dence is insufficient to support widespread home
placement of automated external defibrillators with
high-risk patients. The evidence is more encouraging
for busy public places such as airports, railway sta-
tions, convention centers, major hotels, and large
public assemblies, and high-risk or remotely located
industries with trained safety personnel.

Transtelephonic defibrillation. Transtelephonic
defibrillation is a recently introduced method to
provide early defibrillation. However, it should not
be classified with automated external defibrilla-
tion. In transtelephonic defibrillation a trained family
member or other companion attaches adhesive mon-
tor/defibrillator pads to a person with cardiac complaints or in cardiac arrest. The defibrillator
pads are attached through cables to a home unit that
then transmits the rhythm by telephone cir-

cuity (either hard-wired or cellular) to a remote
base station. Emergency personnel at the base
station interpret the rhythm and make the decision
to deliver a shock. Base station controls can be used
to charge the home defibrillator unit and deliver the
shock. A two-way speaker phone provides simulta-
neous voice communication between the home and
the base station.

Researchers have confirmed this concept of re-

dote defibrillation in hospital settings. Physicians
have attached the device to patients in one
hospital location (usually a coronary care unit for
elective cardioversions) and operated it from an-
other. This approach offers potential advantages over
automated external defibrillators when used in the
home setting, including two-way voice communica-
tion, automatic dialing of 911, and transfer of deci-

dion making to emergency personnel. Although

approved for clinical use, clinical experience con-

firming the effectiveness of prehospital transtele-

phonic defibrillation is limited to a single patient,
widely reported in the lay press. It remains to be
seen whether transtelephonic defibrillation will be
considered cost-effective and put to major practical
use. This doubt is especially valid since clinicians
have already confirmed the ability of automated
defibrillators to interpret rhythms and de-

liver shocks satisfactorily.

The Early Advanced Cardiac Life Support Link
In many instances CPR and defibrillation alone do
not achieve or sustain resuscitation. The unique
interventions of the early advanced cardiac life sup-
port link—endotracheal intubation and intravenous
medication—are necessary to further improve the
chances of survival. In the United States, paramedics
provide advanced cardiac life support for prehospital
cardiac arrest patients. Paramedics receive 1,000–
3,000 hours of classroom training and field instruc-
tion and can provide intubation, defibrillation, and
intravenous medications.

EMS systems in other countries provide many
models of care. Some are more innovative than those
used in the United States. There are no paramedics
as such in Europe. Ambulance personnel in the first
responding units are sometimes provided with exten-
tive training, which may be from 400 to 500 hours.
In Oslo, for example, ambulance personnel (equivalent
to US basic EMTs) are taught to perform endotra-
cheal intubation. In Holland a registered nurse who
can operate a manual defibrillator arrives on more
than 80% of the first-responding ambulances. Other
systems, such as that in Göteborg, Sweden, use a
second responding unit manned by specially trained
nurses on 24-hour duty, similar to a US paramedic
unit. Physician-manned mobile coronary care units
are also common.

In other locations, especially in France, Israel, and
Germany, and to a much lesser extent in England,
Australia, and Finland, emergency physicians (called
ambulance doctors) provide advanced cardiac life sup-
port. In Paris, for example, specially equipped vehicles,
known as doctor-manned ambulances. Systems in the
United States, however, abandoned programs with
physicians or nurses on ambulances years ago because
physician-staffed ambulances in the United States
were considered an inefficient use of physician re-
sources. In addition, paramedics can perform the
same functions with comparable effectiveness.

Physician-staffed ambulances in Europe, however,
may well be more cost-effective than they are in the
United States, depending on relative operating costs,
professional salaries, population density, and com-
bined services such as air rescue. In Norway, for
example, nine doctor-ambulance units combined
with helicopter services respond effectively to about
4,500 patients a year in a population service area of 4
million people. These units depend on public sub-
scriptions and have been quite popular. In Australia
several states and localities use a single-layer ambu-
lance response. The ambulance training, however,
includes both early defibrillation and administration
of up to 20 drugs (but not intubation). The guiding
principle in all systems, no matter how organized, is
to provide the necessary treatment to the patient in
the most timely and cost-effective manner.
Defibrillation and advanced cardiac life support. Observers classically have considered defibrillation a part of advanced cardiac life support care. Now, however, early defibrillation is a separate link in the chain of survival. EMTs and other early responders share this skill with paramedics, physicians, and nurses. Still, in view of the simultaneous therapies employed during a resuscitation attempt, it is difficult to separate the value of defibrillation from the value of intubation and intravenous medications.

What incremental benefit can be derived from these advanced procedures compared with defibrillation alone? Evidence from different locations, with different emergency response systems, sheds some light on this question. Differences in survival rates exist between a system that provides only early defibrillation and a system that provides both early defibrillation and early advanced cardiac care. These differences may indicate the additional benefit of advanced cardiac life support. In Iowa, for example, small communities that have provided early defibrillation without prehospital advanced cardiac life support care have achieved a ventricular fibrillation survival rate of 19%. Meanwhile, suburban King County, Washington, which uses a tiered system (early defibrillation crews followed by advanced cardiac life support crews), has achieved an even greater survival rate. This system reports a 29% survival rate for patients with witnessed ventricular fibrillation arrest. Emergency personnel resuscitated about 30% of persons who survived with defibrillatory shocks alone, either from emergency medical technicians trained to defibrillate (EMT-Ds) or from paramedics. These people did not require subsequent intubation or intravenous medications.

The average survival rate for EMT-D–only systems has been 16% (see Table 3). This rate refers to patients in witnessed cardiac arrest and in ventricular fibrillation. This is significantly lower than the average ventricular fibrillation survival rate of 29% in combined EMT-D and paramedic systems. Paramedic-only systems have an average survival rate of 17%, almost exactly the same survival rate as EMT-D–only systems. Paramedic-only and EMT-D–only systems average the same survival rate for a specific reason. In paramedic-only systems all advanced cardiac life support interventions (defibrillation, intubation, and administration of medications) are performed, but performed late. Only basic CPR and defibrillation are performed in EMT-D–only systems, but these interventions are performed much earlier.

These observations confirm that a considerable portion of all survivors are alive because of early defibrillation alone. These data also imply the important additional value of intubation and intravenous medications. Researchers think that these interventions not only promote return of spontaneous rhythm and circulation but also stabilize and maintain patients during the immediate postresuscitation period. Ventricular fibrillation survival rates in EMT-D–only systems (Table 3) can be compared with survival rates of tiered EMT-D/paramedics systems. Such a comparison hints at the relative value of these two system types. The table shows that EMT-D systems alone resuscitate about half of all potential ventricular fibrillation survivors.

Systems already staffed with paramedics or, as in Europe, with doctor-manned ambulances should consider the addition of a basic EMT- or ambulance-defibrillation program, which may significantly increase the ventricular fibrillation survival rate. However, no system should delay the start of an early defibrillation program because of the absence of paramedics or doctor-manned ambulances. In fact, some paramedic-only or doctor-manned systems have such long response times and such poor outcomes that they may be abandoned in favor of or supplemented by early automated defibrillation.

Resources may prevent establishment of a tiered response system that includes first-responder defibrillation as well as paramedics. In these circumstances, first-responder defibrillation, rather than paramedics alone, is probably the most efficient method to improve survival from cardiac arrest. For locations without an effective method of rapid deliv-
ery of prehospital defibrillation, the rational approach is to start with first-responder automated defibrillation. Innovative leaders in such locations as Japan, Scotland, Singapore, England, Norway, Australia, and Hong Kong have all abandoned inappropriate plans to institute or continue paramedic systems. Instead, these programs are going directly to the more efficient and more effective approach of automated defibrillation.

Commentary

What is the maximum practical survival rate? The number of people resuscitated from sudden cardiac death by emergency personnel is not known. Nor is it known how many people can be resuscitated with a reasonable chance of surviving and remaining neurologically intact. Cardiac disease, in general, is the single greatest cause of death in the United States. For the adult American population, epidemiologists have estimated the annual incidence of out-of-hospital sudden cardiac arrest at about 1 in 1,000 per year. Other statistics from the American Heart Association are often quoted: 1.5 million "generic" heart attacks per year in the United States, of which 25%, or 350,000–400,000, die out of the hospital. Though no national averages are available on the proportion of people who survive out-of-hospital cardiac arrests, current estimates suggest that no more than 1–3% of victims live to be discharged from the hospital. The true percentage is probably even less.

It could be argued that the highest survival rates currently reported for out-of-hospital cardiac arrests are a reasonable target for all locations. While achievements of such survival rates are not practical in every community, this approach does expose the gap between what a community does achieve and what is possible. The highest published rates come from sophisticated urban/suburban systems like King County, Washington, and Seattle. Both can be described as mature EMS systems. Over the past 10–15 years these locations established strong links in the chain of survival. The annual survival rates for King County, Washington, from 1976 through 1987, fluctuate between 15% and 20% for all cardiac arrests and 25–30% for all patients in ventricular fibrillation (Figure 2). These overall survival rates, however, have remained moderately stable despite a number of system interventions, such as EMT defibrillation with manual defibrillators, EMT defibrillation with automated defibrillators, dispatcher-assisted CPR, and transturban pacing. Therefore, this level of ventricular fibrillation survival may represent the practical limits for prehospital emergency care.

How many people would survive if all emergency medical systems in the United States approached the hypothesized maximum survival rate of 20% that occurs in these mature EMS systems? If an estimated 3% survival rate is applied to the presumed annual 400,000 cardiac arrests, approximately 12,000 people per year now survive out-of-hospital cardiac arrest. A 20% survival rate for this population of nontraumatic cardiac arrest patients would yield 80,000 survivors, or an additional 68,000 people. The American Heart Association estimates that nationwide implementation of all life-saving emergency cardiac care mechanisms in each community may save between 100,000 and 200,000 lives annually in the United States. Without proper implementation of a full prehospital care system, however, emergency services cannot achieve such rates. People not resuscitated before hospital arrival rarely survive.

Design Imitation?

Is it possible for EMS systems to imitate the design of more successful locations and thus achieve the same survival rates? Table 3 summarizes data published on cardiac arrest survival from many cities worldwide. These data show marked variation in survival rates among the different types of EMS systems, ranging from 5% to 17% survival for patients in all cardiac arrest rhythms and from 12% to 29% for patients specifically in ventricular fibrillation.

Simple structural imitation of successful EMS organizations, however, does not always succeed. Even in locations with similarly structured EMS systems, marked differences in the observed survival rates persist. For example, studies from 15 different paramedic-only or doctor-manned ambulance systems (Table 3, row C) reported survival rates from 7% to 18% for all rhythms and from 13% to 30% for ventricular fibrillation. Table 3 summarizes results from nine EMT-paramedic systems (row D). These systems display the same wide variations.
It is unclear exactly why these differences occur within the same types of systems. Part of the explanation is that definition of terms and reporting of data are not standardized.\(^{159}\) While some researchers have proposed uniform reporting systems, many others have pointed to the need for an international standardized nomenclature.\(^{18,27,35,39,87,159,160}\) Regardless, part of these differences may very well be due to variable effectiveness or lack of EMS medical leadership and direction.\(^{161-165}\)

It can also be argued that similarly constructed systems have different survival rates because they differ in how well they develop and implement each link in the chain of survival.\(^{87,163,166}\) This appears particularly true for early initiation of CPR and early arrival of personnel trained to operate a defibrillator. Many cities in the United States, for example, established a strong link for early advanced life support by starting paramedic services at great expense and effort.\(^{33-35,76-86}\) Most of these paramedic-only systems have achieved disappointingly low survival rates. In part this is because citizens in these locations seldom attempted to perform CPR. In addition, long paramedic response times, in the absence of an early defibrillation program, precluded early defibrillation and early advanced care. In paramedic-only systems, paramedics are generally preoccupied with many other minor emergencies and consequently are less available (and less skilled) to deal with cardiac arrest patients.\(^{163}\)

To strengthen the early CPR link in the chain of survival, several EMS systems have mounted extensive CPR campaigns. They have trained a large percentage of the population in basic CPR skills. Unfortunately, these systems also have observed diminished survival rates because they failed to provide an emergency medical service with rapid defibrillation and rapid advanced life support.\(^{18,39,43,78,153,155}\) Enhancements of early CPR programs, such as targeted CPR training\(^{40,53-59}\) and dispatcher-assisted CPR programs,\(^{51,65,67}\) will also fail if defibrillation does not occur soon after collapse.

Conversely, systems that have established early defibrillation programs by training their less advanced ambulance personnel to use defibrillators\(^{43,90,119,120,142}\) may experience low success rates if they do not also train citizens to recognize cardiac arrest early or to call the emergency service immediately. The defibrillator will not arrive quickly enough if the EMS system is not called immediately, if local ambulances or first-responder units are not equipped with defibrillators, or if managers do not strategically deploy emergency response vehicles with defibrillators.

Responsible people must apply continuous quality improvement concepts to each link in the chain of survival. In early CPR, for example, it is not only a matter of the number of people who are trained. Systems can achieve better results by targeting the right groups and evaluating training programs, short-term results, and long-term trends. Automated defibrillators must be placed, then complemented with carefully planned training and follow-up programs and close medical control of the system, including individual case reviews and overall data management programs. Without these quality improvement methods, a system will not realize the full benefit of any new organization.

**Summary**

The chain of survival concept embodies standard principles of system management. The phrase re-states\(^{167}\) the familiar emergency medical services continuum pioneered by Peter Safar, who coined the term life support chain.\(^{168}\) Other authors have referred to the concept with various phrases.\(^{1,3,20,23,140}\) As a pedagogic construct, it emphasizes that there are no easy, single-step approaches to improving survival from cardiac arrest.\(^{166,167}\)

Early access to the EMS system ensures early CPR, defibrillation, and advanced care. Early access is easiest to achieve with 911 systems and widespread community education and publicity. Instructors may also teach early access during citizen CPR classes. Early CPR helps patients by slowing the process of dying, but its effectiveness disappears within minutes, and defibrillation must soon follow. Early recognition and early CPR are best achieved when citizens are well informed about cardiac emergencies and well trained in CPR. The earliest possible delivery of defibrillation is critical and almost by itself is sufficient for many victims of sudden cardiac death.

Defibrillation has therefore emerged as the single most effective intervention for patients in nontraumatic cardiac arrest. Automated external defibrillators help to accomplish this goal and permit widespread implementation of a variety of early defibrillation programs. Early advanced care helps those who do not immediately convert to an organized cardiacl activity or who do not achieve a spontaneous circulation following early defibrillation. Advanced care allows the highest possible survival rate through respiratory and antiarrhythmic stabilization and monitoring of patients in the post-resuscitation period.

At present, early CPR and rapid defibrillation, combined with early advanced care, can result in long-term survival rates for witnessed ventricular fibrillation as high as 30%. Researchers have observed that neurological and psychological recovery from cardiac arrest depends on the time within which these critical interdependent treatment modalities are delivered.\(^{22,166}\) Therefore, high resuscitation rates will also lead to a high percentage of patients who recover to the neurological level they had before their arrest.

The future of the chain of survival will be highly dependent on multicenter cooperative studies of cardiac arrest in both in-hospital and out-of-hospital settings.\(^{150,162,170}\) In addition to scientific research, the training of those responsible for implementing and maintaining the chain of survival must become a priority.\(^{150,162,164}\) For emergency medical services the challenge is to develop programs that will allow
recognition, access, bystander CPR, defibrillation, and advanced care to occur as quickly as possible. Ideally systems should deliver these interventions within moments after sudden death victims collapse. Achievement of such a goal requires the deployment of multiple, properly directed programs, within an EMS system. Each program should lend strength to the chain of survival, thereby enhancing successful recovery and long-term survival.

Recommendations

The Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee of the American Heart Association recommend that all communities take the following actions to strengthen their Chain of Survival:

1. Early Access
   - All communities should implement an enhanced 911 system.
   - All communities should develop education and publicity programs that focus on cardiac emergencies and a proper response by citizens.

2. Early CPR
   - Communities should continue to vigorously implement and support community-wide CPR training programs.
   - Community CPR programs should emphasize early recognition, early telephone contact with the EMS system, and early defibrillation.
   - Community CPR programs should develop and use training methods that will increase the likelihood that citizens will actually initiate CPR.
   - Communities should adopt more widespread and effective targeted CPR programs.
   - Communities should implement programs to establish dispatcher-assisted CPR.

3. Early Defibrillation
   - All communities should adopt the principle of early defibrillation. This principle applies to all personnel who are expected, as part of their professional duties, to perform basic CPR; they must carry an automated external defibrillator and be trained to operate it.
   - Health professionals who have a duty to respond to a person in cardiac arrest should have a defibrillator available either immediately or within 1–2 minutes.
   - Responsible personnel should authorize and implement more widespread use of automated external defibrillation by community responders and allied health responders.

4. Early Advanced Life Support
   - Advanced life support units should be combined with first-responding units that provide early defibrillation.
   - Advanced life support units should develop well-coordinated protocols that combine rapid defibrillation by first-responding units with rapid intubation and intravenous medications by the advanced cardiac life support units.

Acknowledgments

Over the years many people have contributed to the chain of survival concept. In particular, we want to mention Professor F.W. Ahnefeld of Ulm, Germany, who pioneered the “rescue chain” concept in emergency medical care in the early 1960s.

The Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee thank the following persons for their contributions to this statement: Mickey Eisenberg, Tore Laerdal, Leo Bossaert, Stig Holmberg, Thomas R. Hearne, Judith Reid Graves, Allan Jaffe, Mary Newman, Mary Pat Larsen, and Douglas Austin Jr.

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_Circulation._ 1991;83:1832-1847
doi: 10.1161/01.CIR.83.5.1832

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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