THE AED IN RESUSCITATION: IT'S NOT JUST ABOUT THE SHOCK

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ABSTRACT

The automated external defibrillator (AED), in combination with effective cardiopulmonary resuscitation (CPR), is a critical part of the American Heart Association's "Chain of survival." Newer guidelines have simplified resuscitation and emphasized the importance of CPR in providing rapid and deep compressions with minimal interruptions; in fact, CPR should resume immediately after the shock given by the AED, without the delay entailed in checking for pulse or rhythm conversion. Our experience with the AED aboard aircraft, showing 40% long-term survival with the AED in ventricular fibrillation, demonstrated the safety and efficacy of the device. Despite this and other reports of successful AED deployment, AEDs are not yet available at all public locations. Prospective research, as undertaken by the Resuscitation Outcomes Consortium, will be the key to future refinements of the guidelines and enhanced survival with use of the AED in sudden cardiac arrest.

The "Chain of Survival" (1), defined by early access, early cardiopulmonary resuscitation (CPR), early defibrillation, and early advanced care in cardiac arrest has been promoted broadly by the American Heart Association. Although CPR predated the development of the modern automated external defibrillator (AED), the technique seemed to be relegated to a lower priority after introduction of the modern AED. Recently, CPR has been increasingly recognized as a critical factor in treating cardiac arrest, in combination with the AED. This paper will focus on the AED and its important integration with CPR.

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CPR: PUSH HARD, PUSH FAST, AND MINIMIZE INTERRUPTIONS

The administration of CPR soon after the onset of cardiac arrest is associated with improved survival and better quality of life among survivors. Animal studies have shown that multiple uninterrupted compressions (30 or more) are required to maximize aortic diastolic pressure in such cases (2), and interruptions, such as with ventilation or feeling for a pulse, allow the diastolic pressure to fall and require another series of compressions to regain perfusion pressure. Clinical investigation has shown that compressions must be rapid and forceful, allowing for full chest recoil to generate the negative intrathoracic pressure needed to maximize the return of blood to the heart (3). Observational studies of clinical CPR have shown that ventilation can interrupt compressions by up to 16 seconds (4) and checking for a pulse can interrupt compression by up to 24 seconds (5). For these reasons, the 2005 American Heart Association (AHA) guidelines recommended that the rescuer "push hard, push fast, allow full chest recoil after each compression, and minimize interruptions in chest compressions" (6). This policy of maximizing the quality and the number of compressions with CPR was upheld in the 2010 AHA guidelines, which stated that rescuers should "push hard" and "push fast" and "attempt to minimize the frequency and duration of interruptions in compressions to maximize the number of compressions delivered per minute" (7).

In the US, CPR is under-employed, with bystander CPR rates below 25% in many communities. Reasons for the widespread failure to provide bystander CPR are likely to include panic, concern about disease transmission, confusion about the CPR protocol, and fear of doing harm. Hands-only CPR, performed without ventilation, has the potential to increase the frequency of bystander CPR, especially with 911 operator coaching through the procedure. This technique might also allow the more prompt initiation of CPR and would reduce interruptions in compression. Concerns that compression-only CPR would fail to circulate oxygenated blood have been raised, but counter-arguments cite evidence that adequate oxygen for resuscitation is present in the blood stream at the time of arrest (suggesting that the priority in CPR should be circulation, not ventilation), and that compression alone provides some ventilation. Basic and clinical studies have suggested that hands-only CPR is as effective as traditional CPR, and these data, in combination with the low frequency of bystander-initiated CPR, prompted an AHA Science Advisory that recommended hands-only CPR for untrained rescuers (8).

In 2010, two randomized studies supported hands-only CPR, dem-

onstrating its non-inferiority, and a trend toward benefit with compression-only CPR as taught to naïve rescuers. In Seattle, 15.5% of victims of cardiac arrest were discharged from the hospital after hands-only CPR, as compared with 12.3% receiving traditional CPR (P = NS) (9). A contemporaneous study in Sweden yielded similar results (10). On the basis of these data, the 2010 AHA Guidelines changed the order of CPR from "ABC" to "CAB" (compressions, airway, breathing), and recommended that untrained rescuers perform hands-only CPR (7). It can be hoped that with increased public awareness of the simplified CPR guidelines, the prevalence of bystander initiated-resuscitation will be increased.

LESSONS LEARNED FROM AED USE ABOARD AIRCRAFT

Under the best conditions, of flying over land, it takes a jet 20 minutes to reach a gate, and longer to obtain ground-based medical care. With such delays, person in whom ventricular fibrillation (VF) occurred aboard an aircraft previously had only a remote chance of survival. American Airlines was the first major air passenger carrier to place AED on aircraft, in combination with a program to train all flight attendants in their use. This became an ideal laboratory in which to study the AED in a controlled but remote location.

In 2000, we reported the first 200 uses of the AED aboard American Airlines flights (11). The mean age of passengers for whom the AED was provided was 58 years, and 66% were men. The device was applied for loss of consciousness in 99 cases and in 101 cases it was employed as a monitor for other conditions such as chest pain or dyspnea. A physician was available to assist in resuscitation in 69% of the cases in which the AED was used. Of note, the AED carried on American Airlines flights displays an ECG lead whose signal is recorded from the AED's antero-posterior shock electrodes; this feature is not typical of community-based AED, which operate more as "black boxes," providing audible reports and commands but no ECG display. The AED used by American Airlines was employed on the aircraft in 95% of cases. Five percent of the time the device was taken off the aircraft by a flight attendant for treatment of a patient in the terminal. Today, removal of the AED from the aircraft would not be necessary because all airports in the US have AEDs located throughout their terminals.

Cardiology faculty members at the University of Texas Southwestern Medical Center reviewed the ECG tracings from the American Airlines experience with the AED, representative examples of which are shown in Figure 1. Panel A shows sinus rhythm following brief

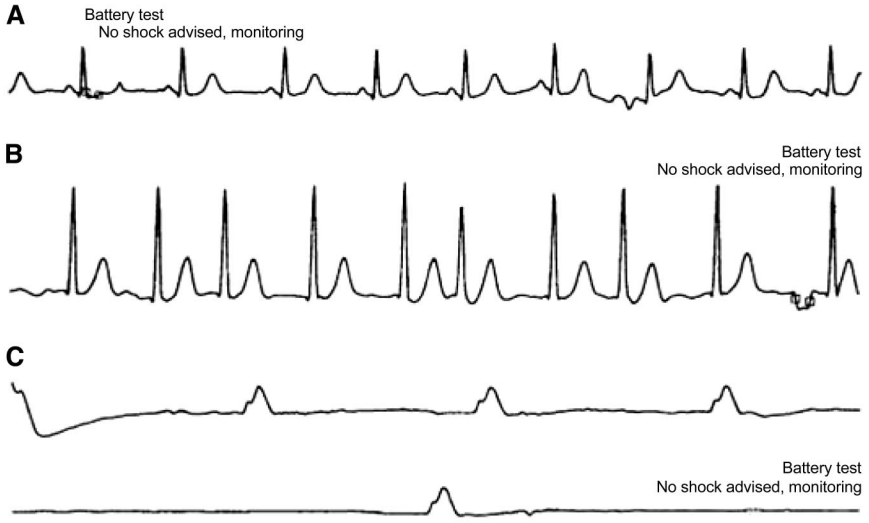

FIG. 1. ECG recordings from AED of passengers who did not have VF and for whom no shock was advised. *Panel A:* sinus rhythm following brief syncope. *Panel B:* AF following syncope and palpitations. *Panel C:* agonal rhythm in an unconscious patient who expired.

syncope in a 45-year-old woman. Figure 1B demonstrates atrial fibrillation (AF) in a 77-year-old man with transient loss of consciousness and palpitations. In contrast to Figures 1A and B, which were recorded from patients who were awake, the recording in Figure 1C was obtained from a 52-year-old male passenger who was unconscious and moribund; it shows an agonal rhythm.

The ECG from the first survivor in the American Airlines experience is shown in Figure 2 (12). The passenger was a tall, overweight man who had a cardiac arrest just after he and his wife took their seats. Despite a protocol that called for removal of the passenger to an aisle or bulkhead, this patient was too large to move and was successfully resuscitated as he lay across the seats. Figure 2A shows conversion of VF with a single shock from the AED after 12 seconds. After 2.5 minutes the patient had a transient 2:1 conduction of sinus rhythm (Figure 2B), and after 10 minutes he was in AF (Figure 2C). The passenger was awake and alert as he was removed by ground ambulance, and he did well clinically. We reported a total of 16 cases of VF, with 14 documented by ECG and 2 presumed; in each case the arrhythmia was appropriately recognized and shock was recommended (100% sensitivity). In one case the patient was terminally ill with cancer and the family requested that no shock be delivered; this wish was re-

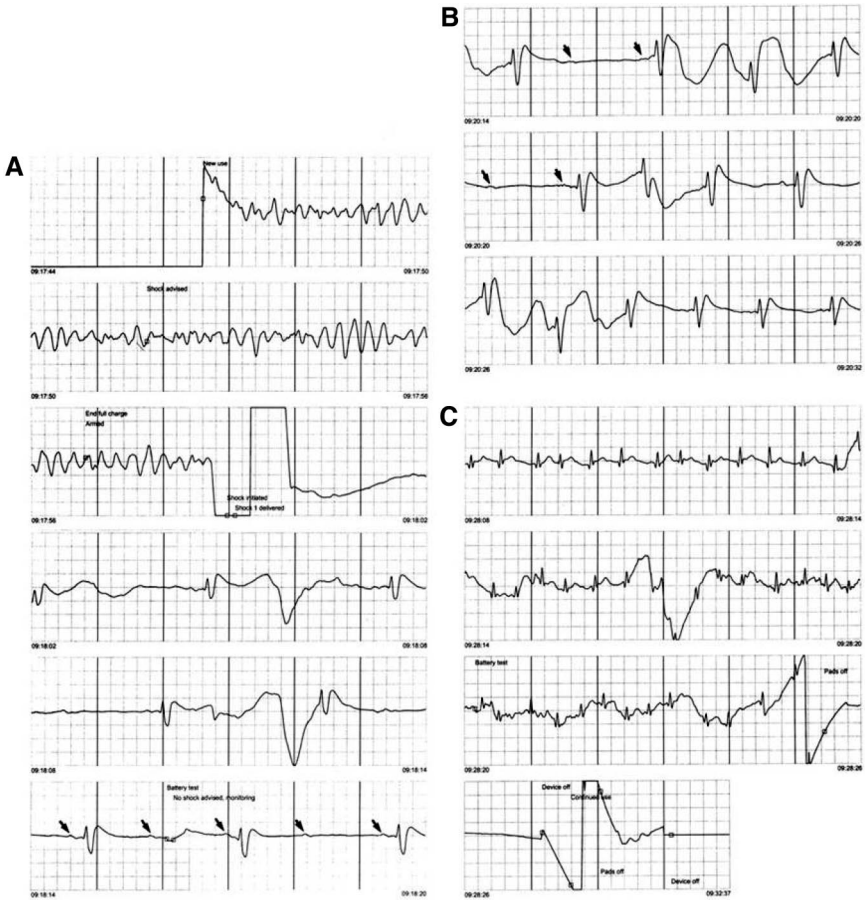

FIG. 2 AED recordings from a patient with VF. *Panel A:* VF is converted after 12 seconds. *Panel B:* sinus rhythm (with arrows on sinus beats) and 2:1 conduction followed by 1:1 conduction. *Panel C:* AF.

spected and the patient expired. In the other 15 patients the arrhythmia was successfully defibrillated, and 6 of these patients survived to hospital discharge. This 40% long-term survival after treatment for VF with the AED is among the highest rates of survival reported in cases of cardiac arrest, and is more remarkable in view of the remote locations in which arrest occurred and the delivery of care by non-medical rescuers (11).

The AED is indicated by the FDA for use only when a patient is unconscious, and as such its use in 101 passengers on American Airlines flights who did not have loss of consciousness was off-label,

but the results provide insight about the safety of the AED. Rhythms other than VF were recorded in 167 passengers. Shock was never either recommended or delivered, providing specificity of 100% for ruling out VF in this series. A further safety feature of the typical AED is that it is automated, as opposed to automatic, so that a shock is not delivered until the operator presses the appropriate button after being instructed to do so. The high specificity and manual override features of the AED suggest that it would be highly unlikely to deliver an inappropriate shock, which should reassure rescuers who might be reluctant to use the device.

USE OF THE AED IN CPR

The first algorithms for use of the AED called for reassessment of the patient's cardiac rhythm after the initial shock, followed by repeated shocks to a total of 3 if needed. After a successful shock, the rescuer was expected to assess the patient for a return of pulse after conversion of the ventricular rhythm. However, the delivery of repeat shocks (if necessary) and checking of the patient's pulse were found to delay the resumption of CPR for 60 seconds or more. Also, even after conversion, the ventricle was often stunned, so that its effective mechanical function did not return with the resumption of sinus rhythm. These issues, along with the finding that the ventricular rhythm was converted to sinus rhythm with the first shock in 85% of cases (13) led the AHA to modify the algorithm so as to specify only a single shock before immediate resumption of CPR, with a check of the patient's cardiac rhythm and pulse only after 3 minutes of continued compressions (14). This change in the resuscitation guideline, like the elimination of rescue breathing, maximizes the time during resuscitation for chest compressions and thus optimizes efforts to provide tissue perfusion.

THE RESUSCITATION OUTCOMES CONSORTIUM

The key to further advancement of resuscitation science is prospective research. For this reason, the National Heart, Lung and Blood Institute of the NIH, the AHA, the Institute of Circulatory and Respiratory Health of the Canadian Institutes of Health Research, and other groups have sponsored the Resuscitation Outcome Consortium (ROC). The Consortium includes 10 centers and 7 satellites in the United States and Canada, allowing prospective multicenter research of both traumatic and cardiac arrest. Studies conducted by the ROC are performed under federal government regulations that allow a waiver of informed consent, with community consent obtained through public

notices in areas of study. First funded in 2006, the ROC has had its grant renewed until 2015.

The first results of research by the ROC were released in 2009; two studies were conducted with a 2-by-2 factorial design. Both studies were discontinued because of lack of meaningful improvement through their findings (15). One study tested the hypothesis, based on earlier clinical studies, that CPR should be administered for 3 minutes before delivery of an AED shock for patients who had delayed initiation of CPR. The second study evaluated whether an impedance valve device on the airway would improve survival by providing a greater negative internal thoracic pressure, and thus increase blood flow, during the relaxation phase of CPR. Although both studies were terminated before their completion, these large randomized studies provided definitive results and data from which to develop future guidelines for use of the AED in CPR.

It is estimated that the participating centers of the ROC cover a population of 21 million people (16). An early report from the ROC compared the outcomes of patients who had an AED used on them before the arrival of EMS personnel with those who did not. In this non-randomized study of 13,769 patients with out-of-hospital cardiac arrest, 32% received CPR alone and 21% had an AED used before the arrival of EMS personnel. Survival to hospital discharge was just 9% with CPR alone, as compared with 24% with used of the AED application and 38% with delivery of shock from the AED. After multivariate analysis, the AED was found to have provided a 1.75-fold greater likelihood of survival (95% CI: 1.23–2.50, $P < 0.002$). Among the total US and Canadian population the AED would be expected to save 474 lives per year.

It is expected that the ROC will continue to provide insights based on the ongoing registry of results of use of the AED; more important, further randomized studies will be undertaken in patients with traumatic and cardiac arrest.

CONCLUSIONS

The AED is a critical component of resuscitation from cardiac arrest, and is especially valuable when combined with effective CPR. Ongoing studies will allow further advances in guidelines for resuscitation; in the meantime, communities should enhance their awareness of cardiac arrest, train lay public in CPR, and distribute AED throughout public locations.

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DISCUSSION

Robertson, Nashville: Rick, that was a wonderful discussion of this important topic that you've had so much to do with over so many years. I wonder if you might comment, now that we do have defibrillators in many airports and in casinos, for example, places where the cardiac risk goes up, what the results of those have been.

Page, Madison: The first casino experience was published back-to-back with our paper. It's interesting in that, in a casino, you are always monitored except when you're in the bedroom and the bathroom, and so they had videotapes of these cardiac arrests. They found that if the defibrillator was applied and shock was delivered within 3 minutes, there was a 75% survival, which is phenomenal. I was very gratified that our reports were published together in 2000, and I like to think that we moved the needle on developing public access to defibrillation in a way that would exceed my ability to have a direct impact on my individual patients. I remain frustrated that places such as this hotel have no AED available, sometimes because of misplaced medical-legal concerns. As I wish you all well on your journeys home, it is striking that you are better off if you have an arrest on your flight today than if you have an event right here.