

## USE OF AUTOMATED EXTERNAL DEFIBRILLATORS BY A U.S. AIRLINE

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### ABSTRACT

**Background** Passengers who have ventricular fibrillation aboard commercial aircraft rarely survive, owing to the delay in obtaining emergency care and defibrillation.

**Methods** In 1997, a major U.S. airline began equipping its aircraft with automated external defibrillators. Flight attendants were trained in the use of the defibrillator and applied the device when passengers had a lack of consciousness, pulse, or respiration. The automated external defibrillator was also used as a monitor for other medical emergencies, generally at the direction of a passenger who was a physician. The electrocardiogram that was obtained during each use of the device was analyzed by two arrhythmia specialists for appropriateness of use. We analyzed data on all 200 instances in which the defibrillators were used between June 1, 1997, and July 15, 1999.

**Results** Automated external defibrillators were used for 200 patients (191 on the aircraft and 9 in the terminal), including 99 with documented loss of consciousness. Electrocardiographic data were available for 185 patients. The administration of shock was advised in all 14 patients who had electrocardiographically documented ventricular fibrillation, and no shock was advised in the remaining patients (sensitivity and specificity of the defibrillator in identifying ventricular fibrillation, 100 percent). The first shock successfully defibrillated the heart in 13 patients (defibrillation was withheld in 1 case at the family's request). The rate of survival to discharge from the hospital after shock with the automated external defibrillator was 40 percent. A total of 36 patients either died or were resuscitated after cardiac arrest. No complications arose from use of the automated external defibrillator as a monitor in conscious passengers.

**Conclusions** The use of the automated external defibrillator aboard commercial aircraft is effective, with an excellent rate of survival to discharge from the hospital after conversion of ventricular fibrillation. There are not likely to be complications when the device is used as a monitor in the absence of ventricular fibrillation. (N Engl J Med 2000;343:1210-6.)

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advances in the design of the automated external defibrillator have made it small, simple to use, and easy to maintain. As discussed at the 31st Bethesda Conference on emergency cardiac care, the use of automated external defibrillators has generally been successful when the devices have been made available to persons other than traditional emergency-response personnel.<sup>4</sup>

Commercial aircraft create a unique environment for the use of the automated external defibrillator. Before the development of the device, emergency response was not available until diversion and landing of the airplane, creating a delay that eliminated all but the most remote chance of survival. Although use of the automated external defibrillator as a monitor is not one of the labeled indications, the device can be used to assist volunteer medical personnel in emergencies in which cardiac arrest is not present. When the automated external defibrillator is on board an aircraft parked at a terminal gate, it can also be used in the emergency care of passengers nearby in the terminal (an environment in which levels of stress and the potential for cardiac arrest are high).<sup>5</sup> The likely benefit of access to defibrillators on aircraft has been weighed against the potential risk to passengers.<sup>6</sup>

In March 1997, American Airlines, a large commercial airline, began to place automated external defibrillators aboard selected aircraft. The program has grown to include the placement of the device on all flights and the training of all 24,000 flight attendants. Training consists of four hours of instruction (one hour in the classroom and three hours in a workshop), followed annually by a one-and-a-half-hour refresher workshop and an examination. Previously, we reported the first successful resuscitation of a passenger with the use of an automated external defibrillator aboard one of the aircraft.<sup>7</sup> We subsequently analyzed the experience of the program, including data on the use of the device in 200 patients.

### METHODS

#### Equipment and Protocol

The automated external defibrillator (Hewlett-Packard Heartstream ForeRunner, model E, Hewlett-Packard [Agilent Technol-

**S**UDDEN cardiac arrest remains a leading cause of death in the United States.<sup>1</sup> Defibrillation performed soon after the onset of cardiac arrest is the most important determinant of survival. As a result, efforts have been undertaken by the American Heart Association to implement programs to ensure public access to defibrillation.<sup>2,3</sup> Recent

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ogies], Seattle) delivers a nonprogressive sequence of three 150-J shocks with a biphasic, truncated exponential wave form and adjusts automatically to the impedance across the chest. The device measures 6 by 22 by 20 cm and weighs 2 kg. The electrode pads are 100 cm<sup>2</sup> in size, and illustrations for placement on the right infraclavicular region and the left lateral wall of the chest are printed on the backs of the electrode pads. A single electrocardiographic tracing is displayed, recorded from the electrode pads. The device is semiautomatic: through a recorded voice, it provides audible analysis and instructions to initiate a shock if criteria for defibrillation are met. A shock is delivered only if the operator presses the button after recommendation by the device.

In response to symptoms that may indicate sudden cardiac arrest (unconsciousness, absence of breathing, and absence of detectable pulse), the flight crew follows a specific protocol for use of the defibrillator. The passenger is moved to the aisle, galley, or bulkhead; clothing covering the chest is removed; and the electrode pads are placed on the chest, which, if necessary, has been cleaned, dried, and shaved. The assistance of medical personnel is solicited, although the flight attendants follow the protocol independently of such advice. The automated external defibrillator may also be used for other medical problems, generally at the request of passengers who are physicians.

**Review of the Event and Analysis of the Data**

After each use of the defibrillator, two specialists in arrhythmia review the data, which consist of the electrocardiogram and files from the medical department of American Airlines. The current analysis includes data from all devices installed on aircraft that were used to evaluate or treat passengers in a medical emergency, both those used aboard the aircraft and those used in the adjoining terminal (when they were the closest defibrillators available).

The study was approved by the institutional review board of the University of Texas Southwestern Medical Center, Dallas. The

board permitted waiver of informed consent because the study involved anonymous data collected for nonresearch purposes.

**RESULTS**

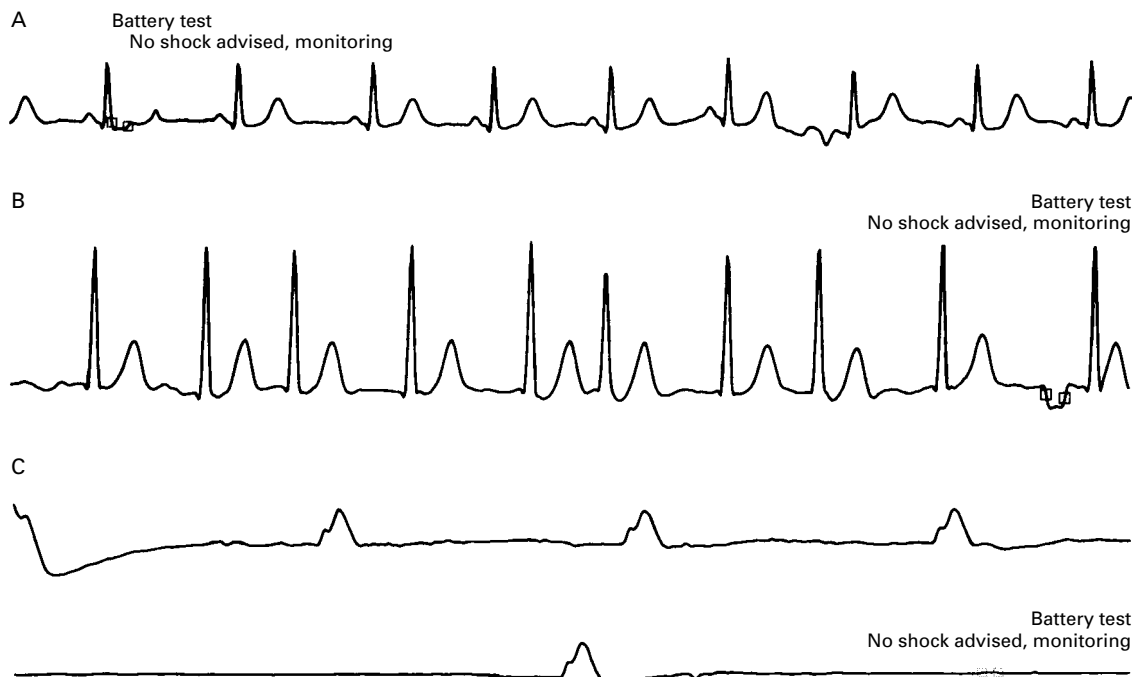
**Characteristics of the Patients**

From June 1, 1997, to July 15, 1999, automated external defibrillators were used on 200 persons (66 percent male; mean age, 58 years), 191 of whom were aboard the aircraft and 9 of whom were in the terminal. Transient or persistent loss of consciousness was documented in 99 persons (49.5 percent). In the remaining persons, the device was placed after a primary diagnosis of chest pain (62 patients), dyspnea (19), nausea or malaise (8), light-headedness (3), palpitations (3), or stroke (1) or for unclear reasons (5). In 139 patients (69.5 percent), a physician assisted.

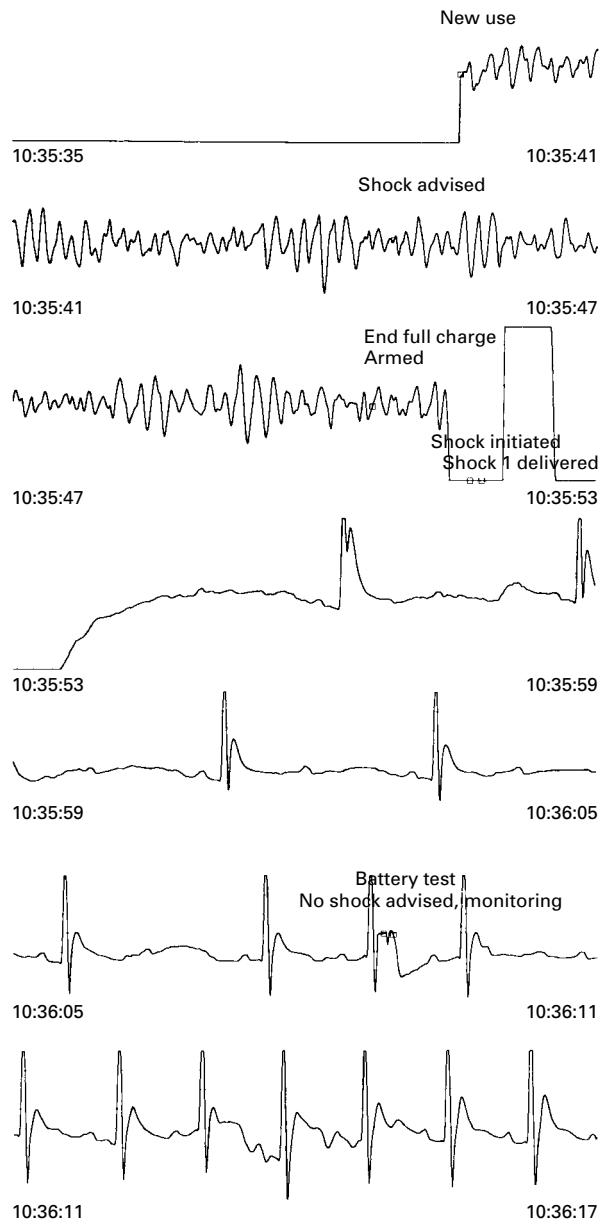
**Electrocardiographic Data**

Among the 200 persons on whom the automated external defibrillator was placed, the device functioned appropriately in all but 1 case, in which a 73-year-old woman reported chest pain and remained conscious. In 14 of the remaining 199 cases, the solid-state memory card of the device failed or was erased inadvertently, leaving a total of 185 electrocardiograms available for review. Sample electrocardiograms are shown in Figures 1 and 2.

In 145 patients, the initial rhythm recorded was a



**Figure 1.** Electrocardiograms from the Automated External Defibrillator for Passengers in Whom Shock Was Not Recommended. Panel A shows sinus rhythm, Panel B shows atrial fibrillation, and Panel C shows agonal rhythm. The patients whose electrocardiograms are shown in Panels A and B survived, but the patient whose electrocardiogram is shown in Panel C did not. The labels shown in each panel depict the activity of the device, including testing of the battery, as displayed on the electrocardiographic tracing.



**Figure 2.** Ventricular Fibrillation as Recorded on an Aircraft. Ventricular fibrillation was successfully converted in this passenger after a total recording of 12 seconds, resulting in a pause followed by sinus rhythm with 2:1 atrioventricular conduction and then normal conduction to the ventricle. The passenger survived to be discharged from the hospital. The labels shown depict the activity of the device, including testing of the battery, as displayed on the electrocardiographic tracing.

sinus rhythm. Bradycardia was present in 14 of these patients, and tachycardia in 21. Atrial fibrillation was found in eight patients, junctional rhythm in three, and supraventricular tachycardia and multifocal atrial tachycardia in one patient each. An agonal rhythm (defined as an idioventricular rhythm at fewer than 30 beats per minute) was seen initially in 13 patients, and ventricular fibrillation was documented in 14 (Fig. 1 and 2).

#### Defibrillator Shocks and Survival

In each of the 14 patients with documented ventricular fibrillation, the arrhythmia was recognized and cardioversion was recommended. Shock was withheld at the family's request in one man who was terminally ill. In the remaining 13 patients, the presenting episode of ventricular fibrillation was terminated with the first shock. Thus, for the documented episodes of ventricular fibrillation, the sensitivity of the device was 100 percent (14 of 14) and success in terminating the first episode was 100 percent (13 of 13). An example is shown in Figure 2. Recurrent fibrillation (for a total of up to eight episodes) occurred in eight patients; each episode was successfully terminated, except in one patient, who had cardiac arrest at the gate before his flight. In this patient, conversion was initially achieved with a single shock. For 20 minutes he received further care from a volunteer physician who was at the scene; during this period the arrhythmia recurred seven times. Each shock was successful until the eighth occurrence of arrhythmia, when fibrillation persisted despite three shocks. The patient was subsequently transferred to a hospital by emergency medical personnel and died.

Two other patients died after shocks were delivered (after three shocks in one patient and after two shocks in another patient), but the electrocardiographic data were lost. Both patients were unconscious, apneic, and without a pulse. The appropriateness of these shocks cannot be assessed, but for statistical purposes these cases have been considered to represent ventricular fibrillation and failed resuscitation.

Of the 15 patients who received shocks (13 for documented and 2 for presumed ventricular fibrillation), 6 (40 percent) were subsequently discharged home with full neurologic and functional recovery. Four of the 15 patients who received shocks had cardiac arrest in the terminal; none of these patients survived. Eleven of the 15 patients had documented or presumed ventricular fibrillation and received shocks aboard the aircraft, with 6 (55 percent) surviving to discharge from the hospital. Electrocardiographic data and outcomes are shown in Table 1.

#### All Deaths and Cardiac Arrests

A total of 36 patients either died or were resuscitated after cardiac arrest (29 on the aircraft and 7 in the terminal). In addition to the 16 with documented

**TABLE 1.** RESULTS OF USE OF THE AUTOMATED EXTERNAL DEFIBRILLATOR IN 200 PASSENGERS ON BOARD AN AIRCRAFT OR AT THE AIRLINE TERMINAL, ACCORDING TO THE INITIAL FINDINGS.\*

VARIABLE	Loss of Consciousness (N=99)					No Loss of Consciousness (N=101)		
	SINUS RHYTHM (N=61)	SVA (N=5)	AGONAL RHYTHM (N=13)	VF (N=14)	NO DATA AVAILABLE (N=6)	SINUS RHYTHM (N=84)	SVA (N=8)	NO DATA AVAILABLE (N=9)
Shock recommended — no.	0	0	0	14	2	0	0	0
Shock delivered — no.	0	0	0	13†	2	0	0	0
Survived to hospital discharge after shock — no. (%)					6 (40)			

\*SVA denotes supraventricular arrhythmia including atrial fibrillation, and VF ventricular fibrillation. One patient for whom no data were available had the defibrillator put in place, but no electrocardiogram was recorded at the scene. In the other cases in which data were not available, the electrocardiogram recorded at the scene was inadvertently erased before it could be reviewed.

†In the case of one passenger, no shock was delivered, at the request of the family.

or presumed ventricular fibrillation, 20 patients died at the scene or after transfer from the airport; none required or received a shock. Thirteen patients initially had agonal rhythms. One patient, who was assessed as having died an hour or more before being discovered, had no cardiac electrical activity and very high transthoracic impedance. Six patients showed initially stable rhythms that deteriorated either while they were being monitored by the defibrillator or after transfer to emergency personnel.

**Use of the Defibrillator as a Monitor**

The automated external defibrillator was placed and recorded an electrocardiogram in 171 patients who did not have ventricular fibrillation and in whom shock from the defibrillator would therefore not have been appropriate. In 101 of 200 cases (50.5 percent), the device was placed without documented loss of consciousness, generally on the recommendation of a passenger who was a physician. In these persons, shock was not recommended by the device and was not administered. Thus, the specificity of the algorithm for the delivery of shock was 100 percent. In 12 patients who survived and did not receive shock, data were recorded but lost; the favorable outcome of these patients suggests that the algorithm appropriately did not recommend defibrillation.

**Frequency of Placement of the Defibrillator**

In the current series, automated external defibrillators were present on 627,956 flights (or for 1442 million km [896 million miles]) carrying 70,801,874 passengers. The number of flights represents less than one full year of travel on American Airlines, which had a total of 792,168 flights in 1998. A defibrillator was used once for every 3288 flights, and a death or resuscitation after cardiac arrest occurred once in every 21,654 flights.

On the basis of these data and industry estimates that American Airlines represents 18 percent of the domestic market and that U.S. air traffic accounts for 45 percent of commercial flights worldwide, we calculated the potential use of automated external defibrillators globally if all commercial planes were so equipped. Our estimates suggest that the device would be used 2975 times for 452 patients with cardiac arrest while on board an aircraft, saving the lives of 93 persons with ventricular fibrillation each year.

**DISCUSSION**

In the first two years after installation, during which the device was used 200 times aboard a U.S. aircraft, the automated external defibrillator performed satisfactorily. The device recognized ventricular fibrillation in 14 patients with 100 percent sensitivity and specificity and terminated every initial episode with the first shock. The rate of survival after defibrillation to discharge from the hospital, 40 percent, compares favorably with the rate of survival to discharge among patients who received a defibrillator shock in other out-of-hospital settings. In addition, the device was safe when used as a monitor; in no case was an inappropriate shock recommended or delivered.

In the past, the number of deaths per year on commercial airlines has not been well defined. The International Air Transport Association reported only 72 deaths per year (the majority of them sudden) between 1977 and 1984, an estimate that is likely to be low<sup>8</sup> since others have suggested that there may be up to 1000 such deaths per year on commercial flights.<sup>9</sup> By an act of Congress,<sup>10</sup> data on emergencies on aircraft were collected for the period from July 1, 1998, through June 30, 1999; the results showed a total of 108 deaths on the 15 major U.S. carriers. Unfortunately, the accuracy of these data is highly variable and the scope of the problem is likely to be un-

derreported.<sup>11</sup> Our data confirm that the number of deaths on aircraft has been underestimated.

The aircraft is a unique setting for cardiac arrest, and air travel may expose or exacerbate medical conditions. Contributing factors include the stress associated with flying, exertion in reaching the gate, disruption of circadian rhythms, and reduced oxygen tension in the cabin (equivalent to that found at an elevation of 1844 to 2576 m [6050 to 8450 ft] above sea level).<sup>12</sup> In addition, the aircraft is poorly designed for the recognition and treatment of cardiac arrest. An unconscious passenger may be assumed to be asleep, so that the cardiac arrest is not noticed in spite of a crowded environment. After the cardiac arrest is recognized, treatment is complicated by difficulty in reaching the patient, noise, vibration, and a lack of privacy.<sup>13</sup>

The most important limitation in delivering treatment to patients with cardiac arrest on board an aircraft has been the lack of availability of advanced-life-support devices. Under the best of circumstances, approximately 20 minutes is required for diversion and emergency landing of an aircraft. Even when the airplane is already on the runway, it may take 10 to 15 minutes to return to the terminal.<sup>14</sup> Such delay in defibrillation translates into a very poor prognosis.<sup>15</sup>

In spite of the potential benefits associated with placing automated external defibrillators aboard aircraft, there has been concern about the associated risks. Issues of passenger or crew safety have been raised, along with the issue of potential injury to the patient. Our experience suggests that there is no basis for such concern.

In 1990 and 1991, respectively, Virgin Atlantic Airways and Qantas Airways began equipping their aircraft with automated external defibrillators. On Qantas, during the first 65 months, 27 passengers had cardiac arrest on board the aircraft; the cardiac arrest was noticed in only 16 of these passengers (59 percent). In 21 passengers (78 percent), the initial rhythm was asystole or pulseless idioventricular rhythm. Six passengers were in ventricular fibrillation; initial conversion was successful in five, of whom two survived for two years or more.<sup>14</sup> In addition to placing the devices on board its aircraft, Qantas placed the devices near its terminal gates. Episodes of cardiac arrest were noticed in 19 passengers in the terminal, and 17 of these patients (89 percent) had ventricular fibrillation as the initial rhythm. Four of these patients (24 percent) survived to discharge from the hospital.

Varig Airlines recently installed automated external defibrillators aboard its aircraft; in the first year (May 1998 to May 1999) the device was used three times for cardiopulmonary arrest. One patient had atrial flutter with high-degree atrioventricular block; two patients with ventricular fibrillation had initial conversion but did not survive. Varig has also placed a separate cardiac monitor without the capacity for

defibrillation aboard its aircraft, to be used when the strict definition of cardiac arrest has not been met (Magalhães P: personal communication).

Our study has two important findings regarding the use of automated external defibrillators by an airline. First, the device can be used effectively to recognize and treat ventricular fibrillation; shock was recommended for each documented episode, and in each patient in whom defibrillation was delivered, the first shock was effective. The survival rate was excellent; 40 percent of the patients survived to discharge from the hospital with intact neurologic function. This rate compares favorably with that obtained by the best emergency medical systems. For example, in Seattle, when firefighters provided initial defibrillation, 30 percent of the patients survived to discharge from the hospital, as compared with 19 percent when defibrillation was provided by paramedics.<sup>16</sup> In other cities, survival rates are much lower, such as 1.8 percent in Chicago.<sup>17</sup>

The survival rate of passengers with cardiac arrest on board an aircraft or at the gate of American Airlines was higher than for Qantas Airways, probably because fewer passengers on American Airlines flights had bradycardia. The difference may relate to the fact that Qantas has longer flights and therefore passengers are more likely to be sleeping or assumed to be asleep (thus delaying emergency care). The experience of American Airlines refutes a possible conclusion from the data on Qantas that cardiac arrest aboard an aircraft, as compared with that occurring on the ground, is more likely to be due to bradycardia.

The second important finding of our study is that the device was safe for use as a monitor. Although it is labeled for use only in cases of apparent cardiac arrest, in more than half of the passengers in our study the automated external defibrillator was used to monitor symptoms other than loss of consciousness. The additional data provided by the device allowed further assessment of the status of the passenger and of the need for diversion or use of the emergency medical kit on the aircraft (which now includes many emergency medications).

There has been concern that the use of the automated external defibrillator as a monitor could result in inappropriate and potentially dangerous electrical discharge, with precipitation of ventricular fibrillation in a previously stable patient. Inappropriate shocks are unlikely to occur, however. We have never documented the inappropriate recommendation of shock, much less its delivery. The semiautomatic feature, which ensures that the shock is delivered only after confirmation of cardiac arrest by the operator, is one safety feature. A further protection against the induction of a lethal arrhythmia by an errant shock is the high success rate of defibrillation. It is well recognized that nonsynchronized shocks can result in ventricular fibrillation (by chance occurrence on the

T wave). However, the theory of an upper limit of vulnerability suggests that ventricular fibrillation will not be induced unless the shock is below the threshold for defibrillation.<sup>18</sup> In view of the high success rate in the current study and in others of defibrillation with the biphasic 150-J shock, even a nonsynchronized shock occurring on the T wave would be unlikely to induce ventricular fibrillation.<sup>19-21</sup>

With the placement of automated external defibrillators on aircraft, new issues of liability have been raised. In response, the Aviation Medical Assistance Act of 1998 was passed, providing immunity for both the airline, for the acts of a medically qualified passenger rendering medical assistance, and the medically qualified passenger, in the absence of gross negligence or willful misconduct.<sup>10</sup> In a definitive treatise on this subject, Ruckman states that "the medically qualified passenger, called upon to assist in an in-flight emergency, should not today be concerned about [his or her] personal liability."<sup>22</sup>

We can expect automated external defibrillators to be on all U.S. commercial flights soon. The Federal Aviation Administration recently proposed that all aircraft capable of carrying 3410 kg (7500 lb) of payload and with a flight attendant be equipped with an automated external defibrillator and an enhanced medical kit.<sup>11</sup> This proposed rule would not be mandatory for 36 months, although major domestic carriers are already placing automated external defibrillators on their aircraft. Recently, Lufthansa was found liable for not providing adequate care to a passenger who had cardiac arrest.<sup>23</sup>

Our findings confirm that a large-scale program by an airline to include automated external defibrillators on commercial aircraft is both safe and effective. We believe that these devices should become standard equipment for all commercial aircraft. Flight attendants must be trained in the use of the defibrillator and instructed to deliver care without delay or interference from medical personnel who volunteer assistance. The use of the automated external defibrillator as a monitor, when requested by qualified medical personnel, appears to be safe; therefore, it is unnecessary to equip the aircraft with a separate monitor (without the capability to provide defibrillation).

The current study has implications for other programs designed to ensure public access to defibrillation. The survival rate in this study compares favorably with that in any other series for which data are available and was achieved in an isolated environment in which nonmedical personnel, most of whom received just one course of instruction, used the device. Another study in this issue of the *Journal* reports on the use of automated external defibrillators by security guards employed in casinos.<sup>24</sup> A recent study showed that untrained sixth-grade students performed almost as quickly as trained paramedics in a trial of automated external defibrillators in mock car-

diac arrest.<sup>25</sup> These findings, along with our data and the data of others, are evidence of the safety and efficacy of widespread placement of these devices as part of a program to enhance public access to defibrillation.

Dr. Page has been a consultant to Hewlett-Packard (Agilent Technologies), the manufacturer of the automated external defibrillator used in this study. The University of Texas Southwestern Medical Center, Dallas, has a consulting relationship with American Airlines for Dr. Page's consultation on the defibrillator program. Dr. McKenas is the Corporate Medical Director of American Airlines.

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