



## Preliminary in-hospital experience with a fully automatic external cardioverter-defibrillator

André Moreira Bento<sup>a,\*</sup>, Luiz Francisco Cardoso<sup>a</sup>, Sérgio Timerman<sup>a</sup>,  
Miguel Antonio Moretti<sup>a</sup>, Eduardo Dante Bariani Peres<sup>a</sup>, Edison Ferreira de Paiva<sup>a</sup>,  
José Antonio Franchini Ramires<sup>a</sup>, Karl B. Kern<sup>b</sup>

<sup>a</sup> Valvular Heart Disease Unit, Instituto do Coração (InCor), University of São Paulo Medical School,  
Av Enéas de Carvalho Aguiar, 44, São Paulo, SP 05403-000, Brazil

<sup>b</sup> Sarver Heart Center, Department of Medicine, University of Arizona College of Medicine, Tucson, AZ, USA

Received 3 December 2003; received in revised form 30 March 2004; accepted 15 April 2004

### Abstract

**Background:** Ventricular fibrillation (VF) and ventricular tachycardia (VT) are frequently present as initial rhythms during in-hospital cardiac arrest. Although ample evidence exists to support the need for rapid defibrillation, the response to in-hospital cardiac arrest remains without major advances in recent years. The delay between the arrhythmic event and intervention is still a challenge for clinical practice. **Objective:** To analyze the performance and safety of in-hospital use of a programmable, fully automatic external cardioverter-defibrillator (AECD). **Methods:** We conducted a prospective study at the Emergency Department of a university hospital. A total of 55 patients considered to be at risk of sustained VT/VF were included. Patients underwent monitoring of their cardiac rhythm by the AECD. Upon detection of a ventricular tachyarrhythmia, the AECD was programmed to automatically deliver shock therapy. **Results:** We recorded 19 episodes of VT/VF in 3 patients. The median time between the beginning of the arrhythmia and the first defibrillation was 33.4 s (21–65 s). One episode of spontaneous reversion of VT was documented 20 s after its origin and shock therapy was aborted. The defibrillation success was 94.4% (17/18) for the first shock and 100% (1/1) for the second shock. No case of inappropriate shock discharge was registered during the study period. **Conclusion:** The AECD has the feasibility to combine long-term monitoring with automatic defibrillation safely and effectively. It presents the possibility of providing rapid identification of, and response to, in-hospital ventricular tachyarrhythmias.

© 2004 Elsevier Ireland Ltd. All rights reserved.

**Keywords:** Cardiac arrest; Automated external defibrillator; Defibrillation; Ventricular fibrillation; Ventricular tachycardia

### Resumo

**Introdução:** A fibrilhação ventricular (VF) e a taquicardia ventricular (VT) estão frequentemente presentes como ritmos iniciais durante a paragem cardíaca intra-hospitalar. Embora exista ampla evidência suportando a necessidade de desfibrilhação rápida, a resposta à paragem cardíaca intra-hospitalar continua sem grandes avanços em anos recentes. O atraso entre o evento arritmico e a intervenção continua a ser um desafio para a prática clínica. **Objetivo:** Analisar o desempenho e segurança da utilização intra-hospitalar de uma desfibrilhador-cardioversor externo totalmente automático (AEC) programável. **Métodos:** Conduzimos um estudo prospectivo no Departamento de Emergência de um hospital universitário. Foram incluídos 55 doentes considerados em risco de VT/VF sustentada. Os doentes tiveram monitorização do seu ritmo cardíaco pelo AECD. O AECD foi programado para administrar automaticamente choque terapêutico se detectasse uma taquiarritmia ventricular. **Resultados:** Registamos 19 episódios de VT/VF em 3 doentes. O tempo médio entre o início da arritmia e a primeira desfibrilhação foi de 33,4 s (21–65s). Foi documentado um episódio de reversão espontânea de VT 20s depois do seu início e o choque terapêutico foi abortado. O sucesso da desfibrilhação foi de 94,4% (17/18) para o primeiro choque e 100% (1/1) para o segundo choque. Não foi registado nenhum caso de choque inapropriado durante o período do estudo. **Conclusão:** O AECD tem a capacidade de combinar de forma segura e eficaz a

\* Corresponding author.

E-mail address: andrebento@cardiol.br (A.M. Bento).

monitorização a longo termo com a desfibrilhação automática. Apresenta a possibilidade de proporcionar a identificação rápida, e a resposta, às taquiarritmias ventriculares intra-hospitalares.

© 2004 Elsevier Ireland Ltd. All rights reserved.

*Palavras chave:* Paragem cardíaca; Desfibrilhador automático externo; Desfibrilhação; Fibrilhação ventricular; Taquicardia ventricular

## Resumen

*Antecedentes:* La fibrilación ventricular (VF) y la taquicardia ventricular (VT) están frecuentemente presentes como ritmos iniciales durante el paro cardíaco intrahospitalario. Aunque existe amplia evidencia para apoyar la necesidad de la desfibrilación rápida, la respuesta al paro intrahospitalario sigue sin mayores avances en los últimos años. El retraso entre el evento arrítmico y la intervención es todavía un desafío para la práctica clínica. *Objetivo:* Analizar el desempeño y seguridad del uso intrahospitalario de un desfibrilador-cardioversor externo programable, completamente automático (AECD). *Métodos:* Condujimos un estudio prospectivo en el departamento de emergencias de un hospital universitario. Se incluyeron 55 pacientes considerados en riesgo de FV/TV sostenida. Los pacientes fueron sometidos a monitorización de su ritmo cardíaco por el AECD. Al detectar una taquiarritmia ventricular, el AECD fue programado para entregar automáticamente terapia eléctrica. *Resultados:* Registramos 19 episodios de VT/VF en 3 pacientes. La mediana de tiempo entre el comienzo de la arritmia y la primera desfibrilación fue 33.4s (21–65s). Se documentó un episodio de reversión espontánea de VT a los 20s después de su origen y la terapia eléctrica fue abortada. El éxito de la desfibrilación fue de 94.4% (17/18) para la primera descarga y de 100% (1/1) para la segunda descarga. No se registró caso alguno de descarga inapropiada durante el período de estudio. *Conclusión:* El AECD tiene la factibilidad de combinar monitoreo de largo plazo con desfibrilación automática segura y efectiva. Presenta la posibilidad de proporcionar rápida identificación y respuesta a taquiarritmias intrahospitalarias.

© 2004 Elsevier Ireland Ltd. All rights reserved.

*Palabras clave:* Paro cardíaco; Desfibrilador automático externo; Desfibrilación; Fibrilación ventricular; Taquicardia ventricular

## 1. Introduction

In-hospital cardiac arrest due to ventricular malignant arrhythmias such as ventricular fibrillation and sustained ventricular tachycardia, is a major cause of morbidity and mortality [1–3].

It has long been recognized that survival from ventricular fibrillation/ventricular tachycardia (VF/VT) is dependent on prompt defibrillation and restoration of a functional rhythm [4–6]. It has been repeatedly observed that survival is inversely proportional to the duration of the potentially fatal arrhythmia [7] as a result of several factors: (1) VF is a frequent rhythm at the start of resuscitation maneuvers; (2) electrical defibrillation is the most effective treatment for VF/VT; (3) the probability of successful defibrillation diminishes rapidly over time;; (4) VF/VT tends to evolve to asystole within minutes [8]. A survival rate as high as 90% has been reported when defibrillation is achieved within the first minute of collapse [9,10]. Survival rates after VF/VT cardiac arrest decrease approximately 7–10% with every minute that defibrillation is delayed. When defibrillation is delayed, survival rates decrease to approximately 50% at 5 min, approximately 30% at 7 min, approximately 10% at 9–11 min, and approximately 2–5% beyond 12 min [8–10].

Although ample evidence exists to support the need for rapid defibrillation and the documented benefits of out-of-hospital use of automated external defibrillators (AED) [11–13], the response to in-hospital cardiac arrest remains without major advances in the last few years. Therefore, the aim of the present study was to analyze

the performance and safety of a full in-hospital automatic external cardioverter-defibrillator (AECD) prospectively.

## 2. Material and methods

### 2.1. Patients

Patients ( $n = 55$ ; 18 years of age or older) considered to be at risk of sustained VT/VF in the emergency department of a university cardiological hospital were included in this prospective study. Inclusion criteria were the presence of at least one of the following diagnosis: acute coronary syndrome (ACS) with elevation of ST segment, ACS without elevation of ST segment, cardiogenic shock with use of inotropic agents, non-sustained ventricular tachycardia or VT/VF at admission or during the in-hospital stay. Patients with previously implanted and activated cardioverter-defibrillator (ICD) or pacemaker were excluded. General data of the patients are shown in Table 1.

Informed consent was obtained for each patient and the study was approved by the local scientific/ethics committee.

### 2.2. Device description

The AECD (Powerheart, Cardiac Science Inc., Irvine, CA, USA) is designed to monitor, analyze, and classify the ECG rhythm of patients continuously. The patient is attached to the device using conventional ECG skin electrodes and two

external defibrillating patch electrodes. This results in three monitoring channels that can be viewed in real time. The operator programs the channel that will be used for rhythm monitoring.

Shock therapy is programmable from 5 to 360 J, using a monophasic damped sinusoidal waveform of fixed duration. Up to 8 sequential shocks can be delivered per tachycardia episode with a programmable delay varying from 10 to 600 s for each therapy. Shock therapy is noncommitted so that if the rhythm spontaneously converts, therapy will be automatically aborted.

The device can be programmed in three operational modes: automatic, advisory or manual. Upon detection of a ventricular tachyarrhythmia, the AECD can provide treatment by automatically delivering cardioversion and/or defibrillation energy in seconds (automatic mode). The AECD can also operate in advisory mode, whereby the device charges the capacitor when a ventricular tachyarrhythmia is detected and prompts the operator to press both shock delivery buttons. The manual mode allows the operator to select the energy, charge the capacitor and deliver the therapy when needed.

Tachyarrhythmias were detected primarily using a programmable rate criterion. Furthermore, for better discrimination of supraventricular versus ventricular rhythms, a modulation domain function, which combines frequency and amplitude content of the signal, was available at the physician's discretion. Each time a ventricular tachyarrhythmia is detected, the device immediately and automatically prints an ECG strip of the episode.

### 2.3. Methods

In addition to the standard care by the institution, patients underwent monitoring of their cardiac rhythm by the AECD using self-adhesive electrodes placed in a conventional base-to-apex configuration after cleaning or shaving the application sites. These defibrillation pads had a surface area of 100 cm<sup>2</sup>. The channel with the largest QRS complexes, smallest T wave amplitude, and least artifact was selected as the detection channel.

Table 1  
General data

Male	71% (39/55)	
Age (years)	64.6 (median)	21–94 (range)
Time between beginning of symptom and monitoring (h)	5.47 (median)	0.5–24 (range)
Time of monitoring (h)	23.51 (median)	4–36 (range)
Diagnosis		
ACS without ST elevation	49.1%	27/55
ACS with ST elevation	25.4%	14/55
VF/VT	14.5%	8/55
Cardiogenic shock	5.5%	3/55
Other	5.5%	3/55

ACS—acute coronary syndrome; VF/VT—ventricular fibrillation/ventricular tachycardia.

The monitoring period could be shortened or extended at the investigators' discretion.

In the present study, the automatic mode was selected for rhythm monitoring, and the shock therapy was programmed according to the International Liaison Committee on Resuscitation (ILCOR) recommended approach [14]. The first shock therapy was programmed to be discharged 20 s after the detection of the tachycardia with a selected energy of 200 J. If the arrhythmia persisted after the first shock, the AECD was programmed to deliver another shock with 300 J after a period of 10 s. In case of failure of reversion after the second shock, a third shock of 360 J was delivered after 10 s. Only these three shocks were programmed, and if the arrhythmia persisted, the device was switched to the manual mode and shock therapy would be selected by the medical staff. Drug therapy and others cardiopulmonary resuscitation maneuvers were based on the ILCOR guidelines [14].

### 3. Results

A total of 55 patients were included in the study and a total of 1293 h of monitoring were performed. The most frequent diagnosis was ACS. Almost half ( $n = 27$ , 49.1%) of the patients had ACS without ST elevation. In this group, only one patient had a malignant ventricular arrhythmia however and this patient was monitored with the AECD only after the event had happened.

The second most common diagnosis was ACS with ST elevation ( $n = 14$ , 25.5%). In this group of patients there was one case of VT on admission that was cardioverted with the use of a manual defibrillator. There were no VF/VT events during the AECD monitoring period.

A total of eight patients were included due to previous VF/VT during their stay at emergency department. Two of them sustained a recurrence of the arrhythmia. One patient presented with 10 episodes of ventricular fibrillation, 9 were successfully defibrillated with the first shock therapy and a second discharge was needed only once. This patient was diagnosed as having dilated cardiomyopathy and required intravenous inotropic agents. Another patient had seven episodes of unstable ventricular tachycardia with loss of consciousness, all successfully defibrillated with the first shock (Fig. 1). Both patients were discharged neurologically intact.

Three patients were included due to cardiogenic shock. One patient, with a previous diagnosis of Chagas cardiomyopathy, suffered two episodes of ventricular tachycardia. One episode spontaneously reverted before shock therapy and the device automatically aborted the discharge (Fig. 2). Another episode of VT was reverted with the first shock therapy.

Other causes for patient inclusion were non-sustained ventricular arrhythmia (two cases) and digitalic intoxication associated with non-sustained ventricular arrhythmia (one case).

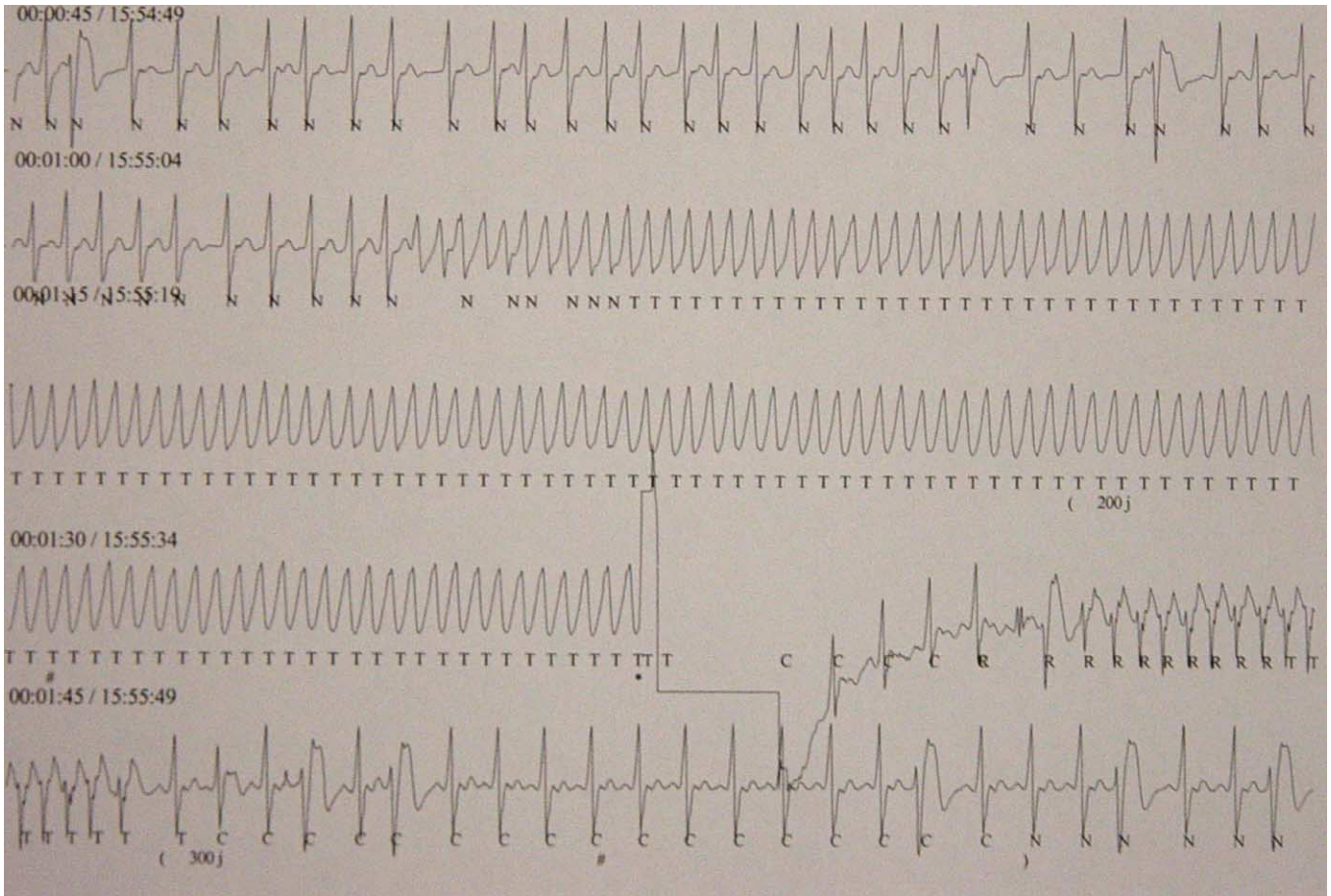


Fig. 1. Recording of the AEDC response to one episode of ventricular tachycardia.

A total of 19 episodes of VF/VT were detected in 3 patients. In 17 occasions the device converted the arrhythmia with the first shock using a 200 J monophasic discharge. The interval varied from 21 to 65 s, with an average of 33.4 s. In one episode of fine VF, the device had a delay in recognizing the rhythm and the first shock was successfully applied 65 s after the beginning of the event.

Only once was a second discharge required, it occurred 25 s after the first discharge and 70 s after the beginning of the arrhythmia. One episode of spontaneous reversion of VT was documented 20 s after its origin and shock therapy was aborted. Successful shock therapy occurred in 94.4% (17/18) for the first defibrillation and 100% (1/1) for the second defibrillation.

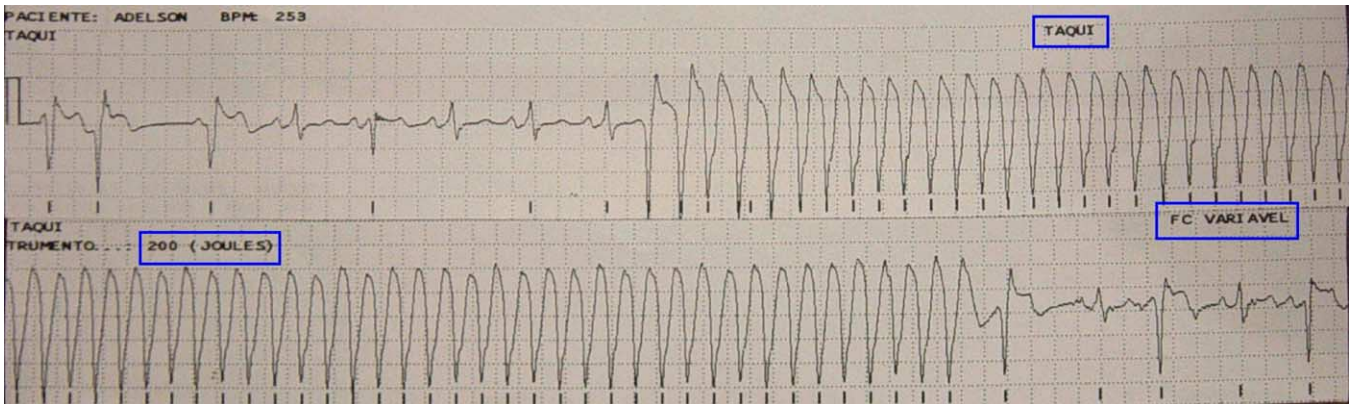


Fig. 2. ECG strip of the AEDC response to one episode of ventricular tachycardia with spontaneous reversion. The first rectangle indicates recognition of the event; the second rectangle indicates the beginning of charge (200 J) and the third rectangle indicates the recognition of the end of the event (therapy was automatically aborted).

We did not register any case of inappropriate discharge during the study period.

#### 4. Discussion

Termination of VF is accomplished relatively easily if its duration is short. The high success rate of first shock therapy with ICDs, or external shocks when immediately available, is widely appreciated [9,10,15]. Defibrillation threshold increases rapidly with duration [16], and studies have shown that survival is improved if the first shock is successful and delivered in a timely fashion [17].

The great frequency of cardiac arrest in the out-of-hospital environment has led to the creation of a device capable of automatically delivering or advising electrical discharges. The out-of-hospital use of AEDs increases the range of personnel who can use a defibrillator, shortening the time between collapse and defibrillation [8]. In last few years, several studies documented the safety and efficacy of the AEDs during out-of-hospital cardiac arrest [11–13,18].

The use of AEDs in early defibrillation programs has been associated with a significant increase in survival rates in a variety of settings, including casinos, airport terminals and commercial aircraft [19–23].

As stated in all major guidelines, early defibrillation is a high-priority goal in both out-of-hospital and in-hospital cardiac arrest [8]. In the in-hospital environment, despite continuous rhythm monitoring and presence of highly trained staff, the response time to ventricular fibrillation has been disappointing. In this setting, using the conventional method of manual defibrillation the often cited interval between the beginning of the arrhythmia and the first shock is about 60 s in monitored areas and 300 s in non-monitored wards [24]. The recognition of time to first defibrillation as a modifiable factor in in-hospital survival has led to efforts to increase use of AEDs and emphasize rapid defibrillation over CPR [8,25].

Only two clinical studies have evaluated this technology [26,27]. Both studies used Holter system for review and confirmation of the patient's rhythms. Each episode documented with the Holter tapes was analyzed and classified as true positive, true negative, false positive or false negative on the basis of the programmed parameters and the device response to the tachyarrhythmia (review of stored data and ECG strips). Both studies showed a highly effective performance and safety of the device, sensitivity was 100% and specificity was about 98%. The average response time was 22 s in the first and 15 s in the second study. The present study has a longer response time because we programmed the device to shock 20 s after the arrhythmia recognition. We used this approach based on the fact that some of the malignant arrhythmias may convert spontaneously, a fact that occurred once in this study, preventing an unnecessary shock therapy. Moreover, the response time of the present study

(33.4 s) is still better than the normal for monitored areas (about 60 s) [24].

For any fully automatic defibrillator used in long-term monitoring application, a highly specific response is fundamental. In this setting, the AED is attached to conscious patients without any restrictions on movement; therefore, the ability to provide artifact immunity is essential. The AED was specifically designed to be highly resistant to artifact through its unique structure and properties, allowing full patient mobility within the limits of the 15 feet (approx. 5 m) cable length. In previous studies [26,27], despite a combined monitoring period of hundreds of hours, there were no episodes of shock delivery or advice in response to artefact. The present study did not register any episodes of inappropriate therapy or adverse events. It is important to note that in our study, those patients in the emergency department had no restrictions on movement beyond those normally incurred in their course of treatment. In spite of this freedom, artefact and motion resulted in no false events.

In wards, cardiac arrest is associated with a very high morbidity and mortality [24], reflecting a lack of human resources. Thus, very rapid interventions with AED could reduce the impact on the clinical outcome associated with cardiac arrest. To place an AED on every patient would require an enormous number of these devices. However, it is possible to select a specific number of high-risk patients that can be monitored by an AED. High-risk patients without haemodynamic compromise, such as patients admitted for ICD implantation or waiting for heart transplantation may benefit from this new technology.

#### 5. Conclusion

The AED offers the opportunity to combine long-term monitoring with automatic defibrillation safely and effectively. It presents the possibility of providing consistently rapid identification and response to in-hospital ventricular tachyarrhythmias. It is likely that the use of this technology has the potential to improve the response time to these life-threatening arrhythmias.

#### References

- [1] Bedell SE, Delbanco TL, Cook EF, Epstein FH. Survival after cardiopulmonary resuscitation in the hospital. *New Engl J Med* 1983;309:569–76.
- [2] Kaye W, Mancini ME. Improving outcome from cardiac arrest in the hospital with a reorganized and strengthened chain of survival: an American view. *Resuscitation* 1996;31:181–6.
- [3] Thel MC, O'Connor CM. Cardiopulmonary resuscitation: historical perspective to recent investigations. *Am Heart J* 1999;137:39–48.
- [4] Eisenberg MS, Copass MK, Hallstrom AP, et al. Treatment of out-of-hospital cardiac arrest with rapid defibrillation by emergency medical technicians. *New Engl J Med* 1980;302:1379–83.
- [5] Kerber RE, Sarnat W. Factors influencing the success of ventricular defibrillation in man. *Circulation* 1979;60:226–30.

- [6] Eisenberg MS, Bergner L, Hallstrom A. Paramedic programs and out-of-hospital cardiac arrest. Factors associated with successful resuscitation. *Am J Public Health* 1979;69:30–8.
- [7] Herlitz J, Bang J, Holmberg M, Axelsson A, Lindkvist J, Holmberg S. Rhythm changes during resuscitation from ventricular fibrillation in relation to delay until defibrillation, number of shocks delivered and survival. *Resuscitation* 1997;34:17–22.
- [8] American Heart Association and International Liaison Committee on Resuscitation. Guidelines 2000 for cardiopulmonary resuscitation and emergency cardiovascular care. Part 4. The automated external defibrillator. Key link in the chain of survival. *Circulation* 2000;102(Suppl 1):60–76.
- [9] Haskell WL. Cardiovascular complications during exercise training of cardiac patients. *Circulation* 1978;57:920–4.
- [10] Fletcher GF, Cantwell JD. Ventricular fibrillation in a medically supervised cardiac exercise program: clinical, angiographic, and surgical correlations. *JAMA* 1977;238:2627–9.
- [11] Cummins RO, Eisenberg M, Bergner L, Murray JA. Sensitivity, accuracy, and safety of an automatic external defibrillation. *Lancet* 1984;2:318–20.
- [12] Auble TE, Menegazzi JJ, Paris PM. Effect of out-of-hospital defibrillation by basic life support providers on cardiac arrest mortality: a metaanalysis. *Ann Emerg Med* 1995;25:642–8.
- [13] Weaver WD, Hill D, Fahnenbruch CE, et al. Use of the automatic external defibrillator in the management of out-of-hospital cardiac arrest. *New Engl J Med* 1988;319:661–6.
- [14] American Heart Association in Collaboration with the International Liaison Committee on Resuscitation (ILCOR). Guidelines 2000 for cardio pulmonary resuscitation and emergency cardiovascular care. An international consensus on science. *Resuscitation* 2000;46:1–447.
- [15] Hossack KF, Hartwing R. Cardiac arrest associated with supervised cardiac rehabilitation. *J Card Rehab* 1982;2:402–8.
- [16] Winkle RA, Mead RH, Ruder MA, Smith MA, Buch WS, Gaudiani VA. Effect of duration of ventricular fibrillation on defibrillation efficacy in humans. *Circulation* 1990;81:1477–81.
- [17] Dalzell GW, Adgey AA. Determinants of successful transthoracic defibrillation and outcome in ventricular fibrillation. *Br Heart J* 1991;65:331–6.
- [18] Niskanen RA. Automated external defibrillators: experiences with their use and options for their further development. *New Horiz* 1997;5:137–44.
- [19] Karch SB, Graff J, Young S, Ho CH. Response times and outcomes for cardiac arrests in Las Vegas casinos. *Am J Emerg Med* 1998;16:249–53.
- [20] Page RL, Joglar JA, Kowal RC, et al. Use of automated external defibrillators by a U.S. airline. *New Engl J Med* 2000;343:1210–6.
- [21] Liu JCZ. Evaluation of the use of automatic external defibrillation in out-of-hospital cardiac arrest in Hong Kong. *Resuscitation* 1999;41:113–9.
- [22] Valenzuela TD, Roe DJ, Nichol G, Clark LL, Spaite DW, Hardman RG. Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos. *New Engl J Med* 2000;343:1206–9.
- [23] Caffrey SL, Willoughby PJ, Pepe PE, Becker LB. Public use of automated external defibrillators. *New Engl J Med* 2002;347:1242–7.
- [24] Herlitz J, Bang A, Aune S, Ekstrom L, Lundstrom G, Holmberg S. Characteristics and outcome among patients suffering in-hospital cardiac arrest in monitored and non-monitored areas. *Resuscitation* 2001;48:125–35.
- [25] Kaye W, Mancini ME, Giuliano KK, et al. Strengthening the in-hospital chain of survival with rapid defibrillation by first responders using automated external defibrillators: training and retention issues. *Ann Emerg Med* 1995;25:163–8.
- [26] Mattioni TA, Nademanee KW, Brodsky M, et al. Initial clinical experience with a fully automatic in-hospital external cardioverter defibrillator. *PACE* 1999;22:1648–55.
- [27] Martinez-Rubio A, Kanaan N, Borggrefe M, et al. Advances for treating in-hospital cardiac arrest: safety and effectiveness of a new automatic external cardioverter-defibrillator. *JACC* 2003;41:627–32.