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Role of Automated External Defibrillators (AED) in Sports

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1. Introduction

Sudden cardiac death (SCD) in young athletes is a tragic event with devastating effects on the family, athletic team, and the local community. Unfortunately sudden cardiac arrest (SCA) due to ventricular fibrillation (VF) is often the first manifestation of underlying cardiovascular disorders and is associated with high mortality. Sudden death in sport is rare and is usually due to congenital or hereditary structural and electrical cardiovascular disorders in young athletes (< 35 years), and atherosclerotic coronary artery disease (CAD) in older athletes. There is debate over the most appropriate screening strategy to identify athletes at risk of SCD. Since some cardiac disorders cannot be identified without elaborate and cost-prohibitive pre-participation cardiovascular screening (PPS) programmes, additional strategies such as an effective programming using automated external defibrillators (AED) may be crucial in minimising cardiovascular deaths in athletes. Furthermore PPS would not prevent acquired cases of cardiovascular fatality in sports such as myocarditis, commotio cordis, and heatstroke or electrolyte disturbances. This chapter provides an overview of the magnitude of the problem, causes of SCD in athletes, the efficacy of automated external defibrillator (AED) in managing SCA, and the importance of emergency response planning to ensure effective management of SCA in athletes.

2. Sudden cardiac death & Sudden Arrhythmic Death Syndrome (SADS)

Sudden cardiac death (SCD) is defined as an unexpected, non-traumatic, non-violent event resulting from sudden cardiac arrest (SCA) within six hours of previously witnessed normal health. A sudden cardiac death where no cause of death is found despite detailed examination of the heart by an expert cardiac pathologist is referred to as Sudden Arrhythmic Death Syndrome (SADS).

2.1 Causes of sudden cardiac death in athletes

Cardiovascular disorders remain the most common cause of death in western world. The commonest cause of sudden cardiac death in individuals aged over 35 years is coronary artery disease. In young athletes aged less than 35 years, hypertrophic cardiomyopathy (HCM) is the most common cause of SCD (Maron BJ, 2003). Other causes of SCD that affect heart structurally include arrhythmogenic right ventricular cardiomyopathy (ARVC), dilated cardiomypathy (DCM), coronary artery anomalies, aortic root rupture (can be associated with Marfan's syndrome) and valvular heart disease (Figure 1). According to the Italian data, ARVC accounts for approximately 25% of all cases of SCD in athletes (Corrado et al., 2005). This discrepancy in the prevalence of ARVC between the US and Italy could be attributed to several factors, notably the existence of a legal and mandatory PPS programme in Italy that has proven effective in the early diagnosis of HCM with subsequent disqualification from sport. Most data on SCD in Italy is derived from the Veneto region which is internationally renowned for pathological expertise in the diagnosis of ARVC.

In approximately 4% of all cases of SCD in sport the heart may appear structurally normal. The most commonly implicated conditions in such circumstances include the hereditary ion channelopathies and congenital accessory pathways e.g. long QT syndrome (LQTS), Brugada syndrome, Wolff-Parkinson-White Syndrome (WPW), catecholaminergic polymorphic ventricular tachycardia (CPVT) and Lenegre's disease. Other acquired causes of SCD include electrolyte disturbances, drugs, myocarditis and Commotio Cordis (blunt trauma to chest leading to ventricular arrhythmia).

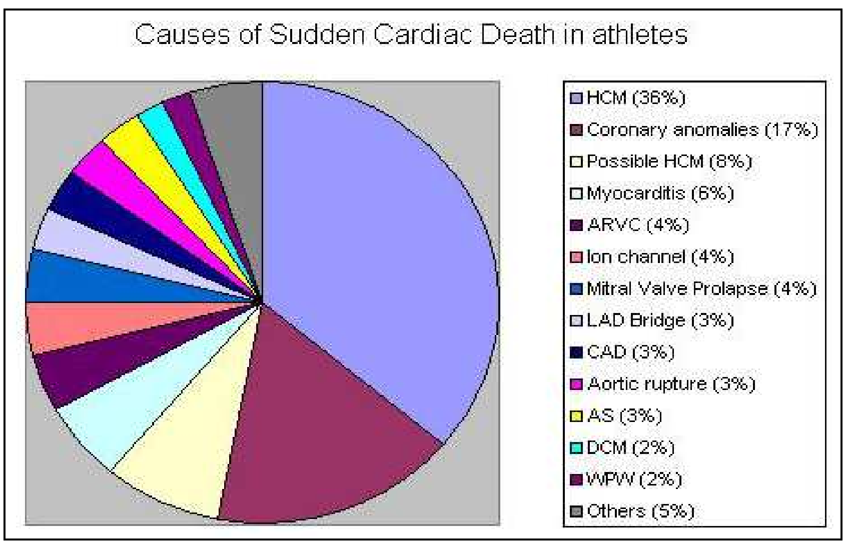

Fig. 1. Causes of sudden cardiac death in young athletes (adapted from Maron *et al.*, 2009). HCM, hypertrophic cardiomyopathy; ARVC, arrythmogenic right ventricular cardiomyopathy; LAD, left anterior descending artery; CAD, coronary artery disease; AS, aortic stenosis; DCM, dilated cardiomyopathy; WPW, Wolff-Parkinson-White syndrome.

2.2 Prevalence of SCD / SCA in athletes

The precise frequency of SCA in athletes remains disputed, but there is general agreement that vigorous exercise is a trigger for SCA in athletes with underlying cardiac disease (Drezner, 2009). The incidence of SCD in young competitive athletes (age 12-35 years) from Veneto region of Italy, was found to be 3.6/100,000 prior to implementation of national screening program (Corrado et al., 2006). In a comparative population study, the relative risk of SCD in young competitive athletes was found to be 2.8 times greater than age-matched non-athletes (Corrado et al., 2003). In general, athletes are perceived as healthier group of individuals compared to non-athletes; however the risk of SCD is higher in this group if they harbour a quiescent cardiovascular disorder. Fortunately these tragic events are rare. Sudden death occurs mostly during or soon after exercise, and has shown to affects males more commonly.

The incidence of SCA in high school student athletes was found to be 4.4/100,000 in a survey of US high schools with AED (Drezner et al., 2009), and was reported as 3.75/100,000 for children and young adults (age 14-24 years) in a prospective, population-based study in US and Canada (Atkins et al., 2009).

3. Role of pre-participation cardiovascular screening (PPS)

A majority of cardiac conditions implicated in SCD may not cause any symptoms prior to cardiac arrest; therefore the only way to detect these abnormalities is by testing or screening healthy individuals. This makes the role of pre-participation cardiovascular screening (PPS) important in young healthy individuals particularly those participating in sporting activities. Identification of high risk individuals based purely on health questionnaire focusing on cardiovascular symptoms has a low yield. The addition of 12-lead ECG as a screening tool to identify young apparently healthy individuals at risk of sudden death increases the diagnostic yield of such screening programmes but increases the false positive rates. There is also considerable resistance to implementation of widespread cardiovascular screening of athletes due to low incidence of SCD in athletes and low prevalence rates of implicated cardiac disorders thus challenging cost effectiveness of such programmes. There is also an overlap between physiological adaptation to exercise and cardiac disorders which may result in false positive results causing unnecessary anxiety and the need for further evaluation and the potential for unfair disqualification from competitive sports.

PPS is not mandatory in UK and most western countries. In USA and Italy, PPS programmes are in existence to minimise risk of SCD in athletes. The US screening protocol comprises of a health questionnaire about cardiac symptoms and family history, and physical examination. Italian screening model includes 12 lead ECG in addition to the health questionnaire and physical examination. A state-sponsored cardiac screening programme has been in place in Italy since 1970s. Recent experience from Veneto region of Italy has shown a significant reduction in SCD in athletes (Figure 2) from cardiomyopathies and heart rhythm disorders since the implementation of nationwide pre-participation screening programme (Corrado et al., 2006).

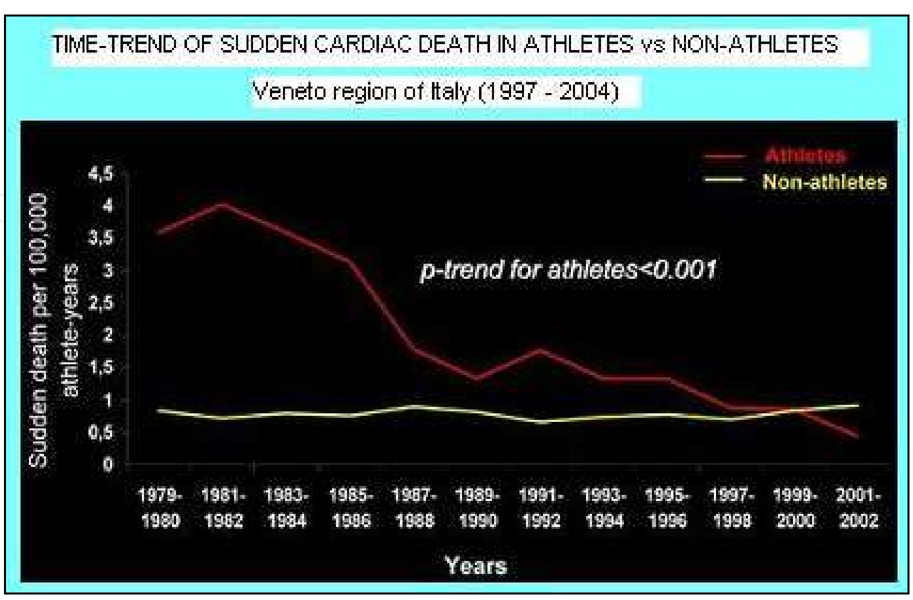

Fig. 2. Annual incidence rates of SCD in screened competitive athletes and unscreened non-athletes aged 12 to 35 years in Veneto region of Italy after introduction of nationwide PPS programme. *(Adapted from Corrado et al., 2006)*

4. The role of automated external defibrillators (AED)

The majority of out-of-hospital cardiac arrests occur by the initial mechanism of ventricular fibrillation (VF) and in some occasions ventricular tachycardia (VT) with loss of cardiac output (pulseless VT); therefore community based portable defibrillators, since becoming first available in late 1960s, have emerged as one approach to this problem. As discussed previously, pre-participation cardiovascular screening (PPS) using ECG may not identify certain cardiac disorders e.g. premature coronary artery disease, anomalous coronary arteries and valvular heart disease, and certain acquired conditions are also implicated in SCD in athletes e.g. myocarditis, commotio cordis and electrolyte imbalance. Therefore it is important to have alternative strategy for secondary prevention of SCD. Automated external defibrillators (AED) have thus become an important part of overall management of victims of cardiac arrest particularly in public places and in sports and fitness centres.

AEDs are sophisticated, reliable and computerised devices capable of delivering electric shocks to victims of cardiac arrest when ECG shows a shock-able rhythm (VF or pulseless VT). A key feature of AED is the simplicity of its operation; controls are kept to a minimum, and voice and visual prompts are used to guide rescuers. Modern AEDs are suitable to be used by both lay rescuers and healthcare professionals (Resuscitation Council UK, 2010).

AEDs can be semi-automatic or fully automatic (example shown in Figure 3). All AEDs can determine victim's ECG and determine the need for shock. A semi-automatic AED indicates the need for a shock which is then delivered by the operator. The automatic AED administers shock without the need for intervention by the operator. Some semi-automatic AEDs have the facility to enable the operator to override the device and deliver a shock manually (Perkins & Colquhoun, 2010).

Fig. 3. Defibtech Lifeline Automated External Defibrillator.

4.1 Time chain of survival

The American Heart Association (AHA) emphasises the time-sensitive intervention for victims of SCA and has outlined four critical steps in a "Chain of Survival" to save lives in the event of cardiovascular emergency (Figure 4). The chain of survival includes a series of actions designed to reduce mortality associated with cardiac arrest. The important links in this sequence include (1) early recognition of cardiorespiratory arrest, (2) early CPR, (3) early defibrillation when indicated, and (4) early advanced cardiac life support.

Fig. 4. Important links in the "chain of survival".

The single greatest factor affecting survival from SCA is the time interval from cardiac arrest to defibrillation (Balady et al., 2002; Drezner et al., 2007). Survival rates from out-of-hospital cardiac arrests have improved since the introduction of public access AED programs which have allowed lay rescuers to deliver early defibrillation (Hallstrom et al., 2004).

The ability to recognise cardiac arrest plays a key role in initiation of a successful chain of survival. This can be achieved by basic life support (BLS) training and general awareness amongst general population. A delay in recognition of cardiac arrest in a collapsed athlete or individual can lead to loss of crucial moments that may then translate into a poor outcome. Brief seizure like activity or involuntary myoclonic jerks have been reported in approximately 50% of young athletes with SCA, and thus SCA can be mistaken for a seizure (Drezner et al., 2006). Another challenge includes inaccurate assessment of pulse and respiration. Occasional or agonal gasping can occur in first minutes after SCA and is often misinterpreted. In athletes with SCA, on-going respiration and pulse was reported in approximately 50% cases (Drezner et al., 2006). Therefore careful and prompt assessment and recognition of SCA plays a crucial part in management of cardiac arrest in any situation but particularly in athletes. Early and effective CPR is the best treatment for cardiac arrest until the arrival of AED or advanced life support. It can prevent ventricular fibrillation from deteriorating to asystole, may increase the chance of successful defibrillation, contributes to preservation of heart and brain function, and significantly improves survival (AHA and International Liaison Committee on Resuscitation, 2000 as cited in Balady et al., 2002).

Public access AEDs play an important role in chain of survival by reducing the time delay from cardiac arrest to delivery of shock. A survival rate of up to 90% has been reported in victims of VF cardiac arrest when defibrillation is achieved within first minute (Franklin et al., 1998 as cited in Balady et al., 2002). Survival rates decline 7-10% with every minute delay in defibrillation; beyond 12 minutes the survival may be as low as 2-5% (AHA, 2000 as cited in Balady et al., 2002). The importance of early defibrillation in "chain of survival" by using AED is further emphasised by evidence of high survival rates with use of public access

AEDs in casinos (Valenzuale et al., 2000) and airplanes (Page et al., 2000) in USA, and in public places nationwide in Japan (Kitamura et al., 2010).

4.2 Efficacy of AED in preventing SCD in athletes

As mentioned previously sudden death of a young athlete is a tragic event and attracts media coverage. Pre-participations screening has shown to reduce incidence of SCD in athletes, but it is not widely mandated and certain cardiac conditions cannot be identified on routine ECG. Hence the need for alternative secondary prevention measures; AED plays an important role in preventing SCD in athletes.

Resuscitation in nine intercollegiate athletes with SCA reported a survival rate of only 11% despite witnessed collapse and timely cardio-pulmonary resuscitation (CPR). This study showed a relatively low survival rate despite use of AED. Mean time to defibrillation was 3.1 minutes (range 1 to 7.5 minutes). All arrests happened during or just after exercise. A detailed scrutiny in this series revealed a delay in response times in 44% of cases, and 5 victims had hypertrophic cardiomyopathy (HCM) which may have influenced the low survival rate (Drezner & Rogers, 2006).

Recent evidence from a cohort of 1710 US high schools with an on-site AED program showed an improved survival rate when early defibrillation in young athletes with SCA (Drezner et al., 2009). Letters were sent out to 18,974 schools; of these 2084 replied (11%); 1710 schools had at least 1 AED on site. A survey relating to SCA was conducted in these 1710 schools between January 2006 and July 2007. A total of 36 cases of SCA were reported. Of these 14 victims were high school student athletes with a mean age of 16 years; 22 were older non-students with mean age of 57 years. 35 (97%) cases were witnessed, 34 (94%) received bystander CPR, and 30 (83%) received an AED shock. Mean time from collapse-to-CPR was 1.5 minutes; mean time from SCA-to-shock was 3.6 minutes. Overall 64% survival to hospital discharge was achieved, which made this study the first to suggest an apparent survival benefit from early defibrillation in young athletes with SCA.

In this study a significant proportion of victims of SCA were non-students and represented an older age range. This group comprised of school staff and spectators. This highlights the importance of AED in managing SCA in general population in addition to athletes. As one would expect a large number of spectators at any major sporting event, the availability of public access AED can also improve survival from SCA in such non-athletic population. Hence AEDs should be made readily available at all sporting clubs and facilities. Likewise, AEDs should be present in public places where lay rescuers could use this device to deliver shock in cases of SCA. This is further elaborated in the following section.

Sudden cardiac death may occur as a result of being struck with a blunt projectile object over the anterior left hemi-thorax. This phenomenon is referred to as Commotio Cordis (Latin word meaning ‘agitated heart’). Such blunt trauma can trigger VF or VT and lead to subsequent cardiac arrest. Unfortunately the general survival rate in commotio cordis is approximately 16%, and with early CPR rates of 25% have been seen. In animal models AED had 98% sensitivity for detecting VF and produced 100% termination of arrhythmia in swine struck with baseball. Based on swine model of commotio cordis, the practice of making AED available on-site may have an advantageous effect on outcome.

4.3 Use of AED in public places by healthcare professionals and lay rescuers

Historically the survival rates from out-of-hospital cardiac arrests using standard emergency medical services have been less than 5% in the USA. A majority of out-of-hospital cardiac arrests occur by the initial mechanism of ventricular fibrillation (VF) therefore it would seem reasonable that early public access to defibrillation would result in better survival rates. Since becoming first available in 1960s, AEDs have emerged as one approach towards the issue of out-of-hospital cardiac arrests.

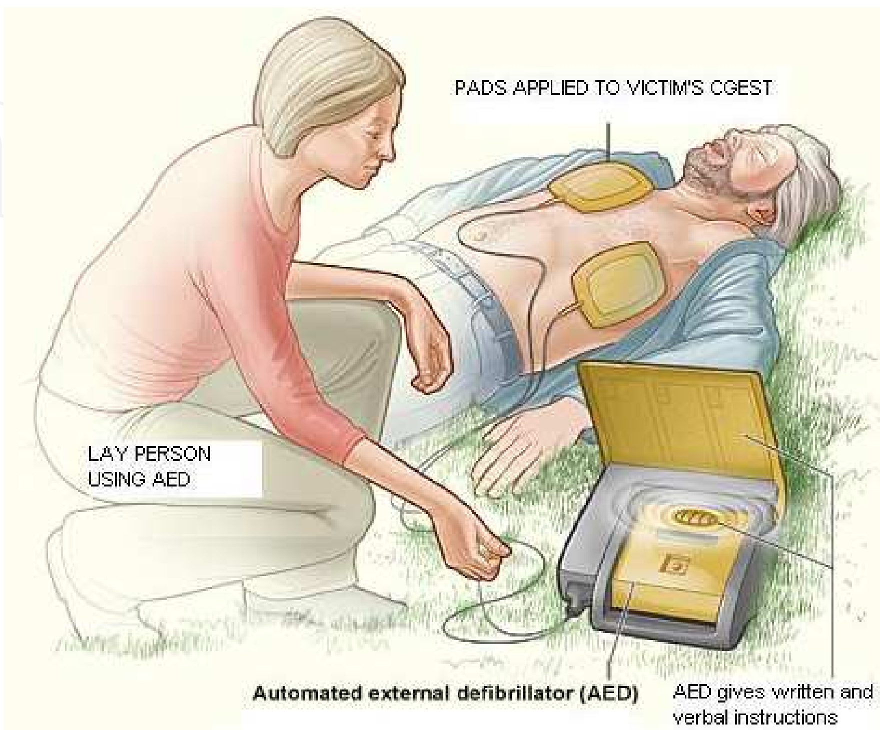

Fig. 5. Demonstration of AED use by lay rescuer.

A high discharge survival rate after out-of-hospital VF with rapid defibrillation by police and paramedics was reported in retrospective observational study in 1990s (White et al., 1996). It was noted that when shock resulted in return of spontaneous circulation (ROSC) without the need for advanced life support (ALS), 96% victims survived. Overall survival rate was 49% (41 out of 84 victims survived); 58% survival rate in police group with mean call-to-shock time of 5.6 minutes and 43% survival rate in paramedic group with mean call-to-shock time of 6.3 minutes. The results of this study showed that early defibrillation not only increases survival from out-of-hospital VF cardiac arrests but increases the likelihood that initial shocks will result in ROSC with the need for costly time-consuming ALS care.
Successful use of public access AEDs by lay rescuers with impressive survival rates has been reported in public places like planes, airports and casinos. These studies not only show that public use of AED is safe but also emphasises the need to encourage use of AED by lay rescuers. The survival rates were similar when AED was used by trained health professionals or by lay people. The single most important factor defining high survival rate was time interval between cardiac arrest to delivery of first shock.
In 1997 a major US airline started equipping its planes with AEDs. From 1997 to 1999, AED was used on 200 occasions; ECGs from all these events were analysed for appropriateness of use; the results suggested that use of AED aboard commercial aircrafts is effective with good survival rate of 40% (Page et al., 2000). During this study AED was also used as a cardiac monitor in conscious patients; no complications or inappropriate shocks were observed in these cases. A 2 year prospective study at 3 Chicago airports showed 56% one year survival

rate with effective use of AED by random bystanders (Caffrey et al., 2002). AED use by casino security guards also demonstrated good survival to discharge from hospital rates of 53% (Valenzuela et al., 2000). In cases of witnessed arrest, mean collapse to shock time was 4.4 minutes. A high survival rate of up to 74% was observed when AED shock was delivered in less than 3 minutes from collapse; 49% survival rate when collapse to shock time was more than 3 minutes.
In a recent study involving over 12,000 victims of out-of-hospital VF cardiac arrest in Japan, nationwide dissemination of AED has shown to increase 1-month survival rates with minimal neurological impairment with early defibrillation by lay rescuers using public access AED (Kitamura et al., 2010). In cases where public access AED was used, 31.6% patients were alive at 1 month with minimal neurological impairment. Mean time to shock decreased with AED being more readily available.

4.4 Emergency Response Planning (ERP)

Emergency response planning (ERP) is required to ensure an efficient and structured response to SCA. It is recommended that every school, club and organisation sponsoring sporting activities should have an emergency response plan for SCA with written policies and procedures (Anderson et al., 2002). The core elements of an emergency response plan (ERP) for SCA include development of a written ERP for SCA, establishment of an efficient communication system, identification and training of likely responders in CPR and AED use, access to early defibrillation by on-site AED, registering AED with local emergency medical services, and annual review of the response plan (Drezner, 2007, 2009). The key elements of ERP are tabulated below.

Key elements of emergency response planning (ERP)
• Develop a written emergency response plan
• Establish an effective and efficient communication system
• Identify and train likely first responders in CPR and AED use
• Access to early defibrillation through on-site AED
• Practice and review EPR at least annually

Table 1. Key elements of Emergency Response Planning (ERP).

The first responder to a medical emergency may widely vary, and may include a coach, official, student, teammate, teacher, school nurse, lay bystander, or a health professional like team physiotherapist, sports medicine professional, trained ALS provider, paramedic or a doctor. All such potential rescuers should be familiar with ERP and should ideally be trained. Coaches and physiotherapists are more likely to be present near the sporting and training activities, therefore they receive training in CRR and use of AED. In high schools, coaches were found to be first responders to SCA in 34% of cases (Drezner et al., 2009). The personnel should particularly be trained to detect and identify SCA in a collapsed athlete. Seizure like activity and occasional agonal respirations have been reported in up to 50% athletes with SCA, therefore a high suspicion of SCA should be maintained in any collapsed individual or athlete (Drezner et al., 2006).

An efficient and easily accessible communication system is important to prevent critical delays in the chain of survival. All parts of school or athletic facility should be developed to enable effective communication for first responder so that an emergency medical service (EMS) can be activated, and on-site emergency response team alerted (Drezner, 2009). Public access AEDs should be located such that collapse-to-shock target of 3 to 5 minutes can be achieved (Drezner et al., 2007). A central location should be chosen with consideration given to most populated areas; multiple AEDs may be needed for large facilities. AED should be highly visible, easily accessible and preferably near a telephone to ensure efficient communication. The equipment should be maintained as per manufacturer recommendations. For large events like distance running, triathlons etc. the location of AED is important; use of bicycles or mobile rescue teams can be helpful (Drezner, 2009).

An ERP should be reviewed at least annually with all potential first responders. Any modifications to the response plan based on drills should be documented. Finally, the ERP should be coordinated with local emergency medical services (EMS), including awareness of types and locations of AED. The latter may be useful for receiving information from EMS about AEDs if an unfamiliar person happens to be the first responder to SCA.

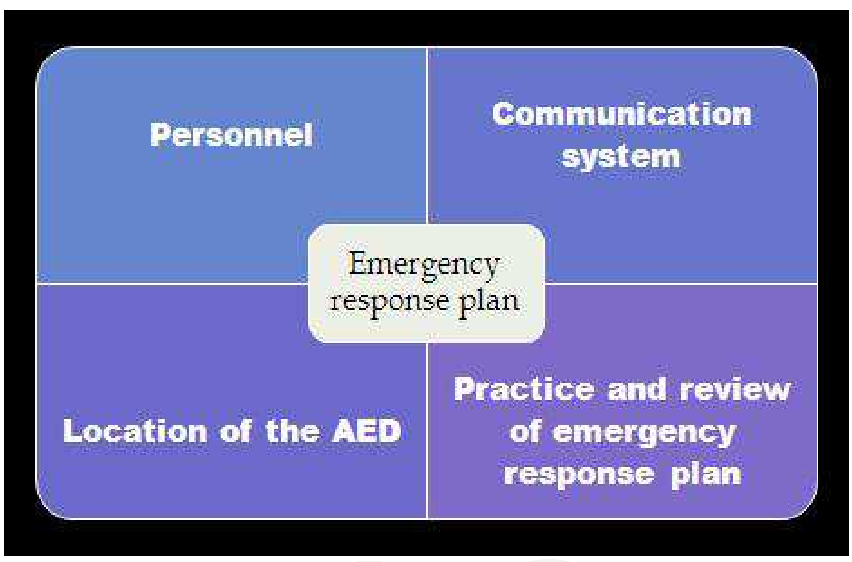

Fig. 6. Emergency Response Planning (ERP).

The European Society of Cardiology (ESC) and European Resuscitation Council (ERC) have been supporting various AED programmes as per ESC-ERC recommendations (Priori et al., 2004). A recent study (Arena study) investigated the cardiovascular safety procedures of major sports arenas in Europe with special attention to the availability of AEDs (Borjesson et al., 2010). A total of 190 football clubs in 10 European countries were included in the study. AED was present in 72% of the venues and 64% clubs reported the existence of a written emergency response plan; only 65% clubs had basic CPR training programme with advanced CPR training programme practiced in only 26% of the clubs. A vast majority (97%) of the clubs had some form of communication system in existence. Furthermore the mean distance from sporting arena to hospital was 4.2km with mean time for transportation of ≤5min achievable in 59% of clubs. Surprisingly, of the 79 clubs with >5min transportation time to hospital, 25% did not have AED on site. The study therefore highlighted the inadequacies in major European sporting clubs in relation to prevention of SCD; 28% of

clubs did not have an AED, 36% did not have a written ERP, 41% clubs had transportation time of over 5min and 25% of these clubs did not have an AED.
Major sporting events attract thousands of spectators including adult and senior individuals with risk factors for cardiac events; these spectators are exposed to intense emotions, and such circumstances have been demonstrated to trigger cardiac events (Chi, 2004 and Wilbert-Lampen, 2008 as cited in Borjesson et al., 2010). During the Arena study, a total of 39.4 million spectators were estimated for 190 clubs. A total 77 sudden cardiac arrests were reported in one season, making estimated adjusted incidence of SCA to be 1 in 589,000 spectators. No cardiac arrests occurred in football players or officials. Therefore the availability of AED as a part of ERP in sporting arenas is crucial for minimising the risk of SCD in both players and members of general public. Efforts are therefore required to further promote AED programmes across Europe and enable sporting venues to implement efficient emergency response planning.

4.5 Recommendations regarding AED use and emergency response planning

There is need for comprehensive emergency planning to ensure an efficient response to SCS in schools, sports clubs and arenas, and public places in general. In US several national recommendations have emerged over time with regards to use of AED and developing an emergency response plan. In 2002 National Athletic Trainers' Association released a position statement recommending any organisation or institution sponsoring athletic activities to develop and implement a written emergency plan for SCA including acquisition of necessary equipment and training of involved personnel in CPR and AED use (Anderson et al., 2002, as cited in Drezner et al., 2009). The American Heart Association (AHA) issued consensus recommendations in 2004 for Medical Emergency Response Plan in schools, emphasising that an AED programme should be in place in every school that cannot reliably achieve call-to-shock time of less than 5 minutes using emergency medical services (Hazinski et al, 2004, as cited in Drezner et al., 2009). American College of Cardiology (ACC) 36th Bethesda Conference suggested that every school providing sports activities should have access to defibrillation within 5 minutes of collapse (Myenburg et al., 2005). In 2007, an inter-association task force strongly recommended access to AEDs with a target collapse-to-shock time of less than 3 to 5 minutes, in a consensus recommendation for emergency preparedness for SCA in high school and college athletic programs (Drezner et al., 2007).
In 2004 the European Society of Cardiology (ESC) and European Resuscitation Council (ERC) joined forces to develop European recommendations for legislation on defibrillation, for training in AED use and for the development of AED community programmes (Priory et al., 2004). Priorities and needs for the prevention of SCD were identified; it was recommended that AED programmes should stem from emergency medical services and hospitals and then progressively move to community programmes; common standards for defibrillation should be set for European countries; legislation regarding public use of AED to be introduced; training requirements for CPR and AED use should be defined for individuals participating in public access AED programmes; the need for systematic data collection and analysis to enable sharing information between various programmes to facilitate research and development; the ESC and ERC should support AED programmes by promoting education in the community. The panel advocated support from ESC and ERC to involve Ministers of Health and the European Parliament in the promotion of a "European Cardiac Arrest Survival Directive".

5. Conclusion

Sudden cardiac death is often the first presentation in an athlete harbouring a potentially sinister cardiac disorder. Prompt identification and disqualification by trained coach or physician can reduce fatality rate significantly. In the current financial climate where resources for pre-participation screening are limited in most countries, consideration should be given to implementation of an on-site AED programme with an adequate emergency response plan. Automated external defibrillators improve survival from sudden cardiac arrest in young athletes and also when used by ley persons and healthcare professionals in public places. The availability of AEDs during competitive sporting events also provides the potential for life-saving support to spectators and other bystanders.

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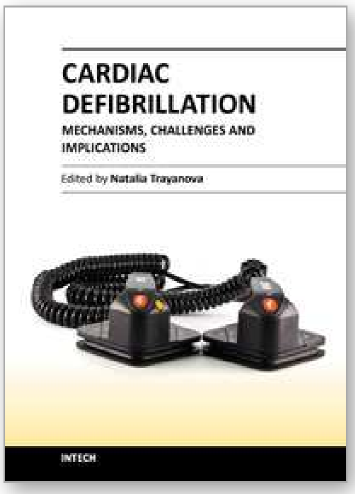

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The only known effective therapy for lethal disturbances in cardiac rhythm is deï¬brillation, the delivery of a strong electric shock to the heart. This technique constitutes the most important means for prevention of sudden cardiac death. The efficacy of defibrillation has led to an exponential growth in the number of patients receiving implantable devices. The objective of this book is to present contemporary views on the basic mechanisms by which the heart responds to an electric shock, as well as on the challenges and implications of clinical defibrillation. Basic science chapters elucidate questions such as lead configurations and the reasons by which a defibrillation shock fails. Chapters devoted to the challenges in the clinical procedure of defibrillation address issues related to inappropriate and unnecessary shocks, complications associated with the implantation of cardioverter/defibrillator devices, and the application of the therapy in pediatric patients and young adults. The book also examines the implications of defibrillation therapy, such as patient risk stratification, cardiac rehabilitation, and remote monitoring of patient with implantable devices.