Preparing for sudden cardiac arrest—the essential role of automated external defibrillators in athletic medicine: a critical review

J A Drezner

Correspondence to:
Dr J A Drezner, University of Washington, Box 354775, 4245 Roosevelt Way, NE Seattle, WA 98105, USA; jdrezner@fammed.washington.edu

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ABSTRACT

Sudden cardiac arrest (SCA) is the leading cause of death in exercising young athletes. Three factors—prompt recognition of SCA, the presence of a trained rescuer to initiate cardiopulmonary resuscitation (CPR) and access to early defibrillation through on-site automated external defibrillators (AEDs)—are critical to improving survival. Schools, clubs and organisations sponsoring athletic events should have an established emergency response plan for SCA. Essential elements of an emergency response plan include an effective communication system to alert first responders and retrieve the AED, training of anticipated responders in CPR and AED use, access to an AED for early defibrillation, integration of on-site AED programmes with the local emergency medical services system, and practice and review of the response plan. Timely access to AEDs at training and sporting competitions permits effective management of SCA and the prevention of sudden cardiac death in athletes. SCA should be suspected in any collapsed and unresponsive athlete and an AED applied as soon as possible for rhythm analysis and defibrillation if indicated. This article reviews emergency response planning for SCA and highlights recent data that provide a compelling case for the essential role of AEDs in the athletic setting.

Sudden cardiac death (SCD) in young athletes is a tragic event with devastating effects on a family, athletic team, and local community. The unexpected death of an athlete during training or competition invariably stimulates review of current preparticipation screening strategies and emergency preparations at athletic events.

The most appropriate screening strategy to identify athletes at risk for SCD remains highly debated and centres upon the inclusion (or not) of a resting 12-lead electrocardiogram (ECG) in addition to a history and physical examination during the preparticipation athletic evaluation.[1–7] However, no screening strategy will identify all athletes at risk for SCD, and recommended screening protocols are often incompletely or inadequately implemented.[8–10] Preparticipation screening that relies solely on a history and physical examination has limited sensitivity to identify athletes at risk for sudden cardiac arrest (SCA), as most athletes with undetected cardiovascular disorders are asymptomatic; SCA may represent the first manifestation of cardiac disease in approximately 60–80% of young athletes with SCD.[11 12] ECG screening will improve the sensitivity of screening to approximately 70%,[13] but some cardiac disorders that predispose athletes to SCD present no abnormalities on a resting ECG. For instance, athletes with coronary artery anomalies of wrong sinus origin account for about 17% of SCD cases and would have normal resting ECGs.[14] In addition, traumatic causes of SCA, such as commotio cordis, which accounts for nearly 20% of SCD in the USA, cannot be prevented through screening.[15]

Thus, there is a critical need for an effective strategy for the management of SCA and secondary prevention of SCD in athletes. This article reviews existing studies and recommendations on emergency response planning for SCA and the utilisation of automated external defibrillators (AEDs) in the athletic setting.

FREQUENCY OF SUDDEN CARDIAC ARREST IN THE ATHLETIC SETTING IS LIKELY UNDERESTIMATED

The exact incidence of SCD in young athletes is unknown. In the US, estimates are limited by the lack of a mandatory reporting system for juvenile sudden death, and past studies vary widely as a result of differences in the methods of data collection, age and the population studied. Previous estimates of SCD in young competitive athletes in the US range from 0.3 to 0.6 per 100 000 athletes per year, have relied heavily on search of public media reports, other electronic databases and catastrophic insurance claims, and have likely underestimated the true incidence of SCD due to the incomplete detection of all cases.[14 16 17]

Other studies with more rigorous reporting mechanisms provide additional data on the incidence of SCD. Findings from the Veneto region of Italy, which utilises a regional registry for juvenile sudden death, found a baseline incidence of SCD in young competitive athletes (age 12–35 years) of 3.6/100 000 prior to the implementation of a national screening programme.[18] In a study of non-traumatic sudden death in US military recruits (age 18–35 years), the incidence of SCD was estimated at 11.1/100 000 after a review of autopsies performed for each case over a 25-year period.[19] A survey of US high schools with AEDs found an annual incidence of SCA of 4.4/100 000 in high school student-athletes.[20] And, in perhaps the most rigorous study methodology to date, Atkins *et al* studied the incidence of paediatric out-of-hospital SCA through a prospective, population-based study with involvement of greater than 260 emergency medical service (EMS) agencies at 11 US and Canadian sites.[21] All cases of SCA with an EMS response were included and population census reports used to calculate the annual

incidence of events. The study found an incidence of SCA due to cardiovascular disease of 3.75/100 000 for children and young adults aged 14–24.[21]

Although the precise frequency of SCA in athletes remains disputed, there is general agreement that vigorous exercise is a trigger for SCA in athletes with underlying cardiac disease. In a comparative population study, the relative risk of SCD was found to be 2.8 times greater in young competitive athletes than in age-matched non-athletes.[22]

The rate of SCA in the school setting is an important determinant of whether school-based AEDs are warranted. Often overlooked in the debate over school-based AEDs is the large number of people who work at schools and attend sporting events who are also at risk for SCA. These individuals are not actively participating in sport but may benefit from school-based AEDs. SCA occurs at a frequency of one in 1000 persons ⩾35 years of age in the US,[21 23] and because a large number of older people attend events at public sporting venues, universities and secondary schools,[24 25] the potential for resuscitation at these sites extends well beyond the athlete participants themselves. The annual probability of an SCA occurring on a high school campus ranges from 2.1% to 4.2% and is mainly due to SCA among older school employees, spectators, and visitors on campus.[20 26] In the high school setting, SCA in older non-students such as spectators, teachers, and school staff represented 61% of SCA cases occurring on school grounds.[20] In the college setting, older non-students such as spectators, coaches and officials accounted for 77% of SCA cases at collegiate sporting venues.[27] Thus, when considering the potential benefit of AEDs in schools and at athletic events, it is crucial to consider that AEDs provide a means of early defibrillation not only for young athletes but also for other individuals at the venue who may experience an unexpected SCA.[20 27 28] Schools—similar to malls, airports and casinos—are strategic locations for AEDs to serve large concentrations of people at risk for SCA.

SURVIVAL AFTER SUDDEN CARDIAC ARREST: RECENT DATA PROVIDE MORE OPTIMISM

The single greatest factor affecting survival from SCA is the time interval from cardiac arrest to defibrillation.[23] In the US, historical survival rates from out-of-hospital cardiac arrest are <5%.[29–31] Survival following SCA has been greatly improved by lay rescuer and public access defibrillation programmes designed to shorten the time interval from SCA to shock delivery.[27 32–39] These programmes train lay rescuers and non-traditional first responders in cardiopulmonary resuscitation (CPR) and AED use, and place AEDs in public locations where risk for SCA is high. Rapid defibrillation in public settings such as casinos, airlines and airports has led to survival rates ranging from 41% to 74% if bystander CPR was provided and defibrillation occurred within 3 to 5 min of collapse.[27 32–39] Essential elements to the success of these programmes include training of anticipated responders in CPR and AED use, a structured and practised response, and short response times.

Limited research is available regarding early defibrillation programmes in the athletic setting. Questions also exist whether early defibrillation in young athletes who suffer SCA from a diverse aetiology of structural and electrical cardiac diseases can provide the same survival benefit as demonstrated in the older general population with a predominance of coronary artery disease as the cause of SCA. Initial research on AED utilisation at college athletic venues found an overall immediate resuscitation rate of 54% in older non-students but did not identify a survival benefit in a small number of intercollegiate athletes with SCA.[27 40] Drezner and Rogers[41] later investigated the timing and details of resuscitation in nine intercollegiate athletes with SCA. Despite a witnessed collapse, timely CPR and prompt defibrillation in most cases, only one of nine (11%) athletes survived—an unexpected finding given that the athletes were young, otherwise in good health and reported early defibrillation.[41] However, close scrutiny of the emergency responses in this series revealed that responding emergency personnel (campus police, firefighters and emergency medical technicians) provided the defibrillator used in the resuscitation in four of the nine (44%) cases—indicating the reported response times may have been underestimated. In addition, five of the nine athletes (55%) had hypertrophic cardiomyopathy (HCM), which likely influenced the low survival rate; cardiomyopathy may become more resistant to delays in defibrillation than SCA in a structurally normal heart (such as SCA from ion-channel disorders or commotio cordis).[41]

Other studies have also found the survival rate after SCA in young athletes to be lower than expected.[42 43] Maron *et al*[42] analysed 128 cases from the USA Commotio Cordis Registry and found an overall survival rate of 16%. Drezner *et al*[44] reported a 7-year analysis of survival trends in the USA following exercise-related SCA in the youth. During the 7-year period from 2000 to 2006, 486 total cases of exercise-related SCA were identified in individuals aged 5–22 with an overall survival rate of 11% (range 4–21%) per year.[44]

However, recent research suggests for the first time an improved survival rate for young athletes with SCA if early defibrillation is achieved. Drezner *et al*[20] reported on a cohort of 1710 US high schools with an on-site AED programme. Thirty-six cases of SCA were described, including 14 cases in a high school student-athlete (mean age 16 years; range 14–17 years) and 22 cases in an older non-student (mean age 57 years; range 42–71 years) such as employees and spectators. All but one case of SCA were witnessed, 94% received bystander CPR, and an AED deployed a shock in 30 of 36 (83%) cases. Twenty-three of the 36 SCA victims (64%) survived to hospital discharge including nine of 14 student-athletes (64%) and 14 of 22 older non-students (64%). Although this was a retrospective cohort study, the consistent reported use of on-site school-based AEDs makes this the largest study of early defibrillation to treat SCA in the school or athletic setting, and the first study to suggest a survival benefit for early defibrillation in young athletes with SCA. In comparison with our previous series in intercollegiate athletes,[41] the higher survival rate reported in high school athletes may be accounted for in part by the higher proportion of SCA victims treated with an on-site AED and the smaller proportion of victims with HCM. An on-site AED was used in the resuscitation of the student-athlete in 11 of 14 (79%) cases, and HCM was only found in three of 14 (21%) cases.[20]

RECOGNITION OF SUDDEN CARDIAC ARREST

Prompt recognition of SCA is the first step to an efficient emergency response. Delayed recognition of SCA by first responders can lead to critical delays or even failure to activate the EMS system, initiate CPR and provide early defibrillation. Resuscitation can be delayed because the victim is reported to have signs of life.[45] Brief seizure-like activity or involuntary myoclonic jerks has been reported in approximately 50% of young athletes with SCA, and thus SCA can be mistaken for a seizure.[20 41] Another challenge to recognising SCA in athletes includes inaccurate rescuer assessment of pulse or respirations. Occasional or agonal gasping can occur in the first minutes after

SCA and is often misinterpreted as normal breathing, especially by lay responders.[46] Occasional gasping does not represent adequate breathing and if present should not prevent rescuers from initiating CPR. Lay rescuers and even healthcare professionals can be inaccurate in assessing signs of circulation and the presence of a pulse. Rescuers with basic CPR training failed to recognise the absence of a pulse in 10% of pulseless victims, failed to correctly identify a pulse in 45% of victims with a pulse and accurately identified pulselessness in only 2% of pulseless victims within 10 s.[47 48] In high school and college athletes with SCA, ongoing respirations or a pulse after collapse were reported in approximately half the cases.[20 41] The 2007 American Heart Association CPR guidelines eliminated lay rescuer assessment of pulse and recommend that cardiac arrest be assumed if the unresponsive victim does not demonstrate normal breathing.[49] Sports medicine professionals and other potential first responders to SCA in an athlete must maintain a high index of suspicion for SCA in any collapsed and unresponsive athlete.

Recognition of SCA due to blunt trauma also may be delayed. Commotio cordis involves a blunt, non-penetrating blow to the chest leading to a ventricular arrhythmia without structural cardiac damage. Commotio cordis occurs most commonly in young male adolescents (mean age 13.6 years) with compliant chest walls.[42] Approximately 80% of cases involve blunt chest impact by a firm projectile such as a baseball, softball, hockey puck or lacrosse ball, and 20% of cases are due to chest contact with another person.[42] Young athletes who collapse shortly after being struck in the chest should be suspected of having commotio cordis and emergency procedures for SCA initiated.[28]

A collapsed and unresponsive athlete should be treated as having had a cardiac arrest until either spontaneous, normal breathing and a pulse are documented or the cardiac rhythm is analysed by a defibrillator. To avoid potentially fatal delays in resuscitation, brief seizure-like activity in a collapsed athlete should be assumed due to SCA unless a non-cardiac cause of collapse can be clearly determined, or the athlete becomes responsive. A high suspicion of SCA must be maintained for any collapsed and unresponsive athlete and an AED applied as soon as possible for rhythm analysis and defibrillation if indicated.[28]

EMERGENCY RESPONSE PLANNING FOR SUDDEN CARDIAC ARREST

Public access to defibrillators and first-responder AED programmes improve survival from SCA by increasing the likelihood that SCA victims receive bystander CPR and early defibrillation. These programmes require an organised and practised response plan with rescuers trained and equipped to recognise SCA, activate the EMS system, provide CPR and use an AED.[33] The American Heart Association emphasises the time-sensitive interventions for victims of SCA and has outlined four critical steps in a ''Chain of Survival'' to save lives in the event of a cardiovascular emergency:[23]

- early recognition of the emergency and activation of the local emergency response system (call 9-1-1);
- early CPR;
- early AED;
- early advanced life support and cardiovascular care (hospital).

Emergency response planning is required to ensure an efficient and structured response to SCA. Every school, club and organisation that sponsors athletic activities should have an emergency response plan for SCA with written policies and procedures.[50] Essential elements of emergency planning include training of anticipated responders in CPR and AED use, establishing an effective communication system, ensuring access to early defibrillation, integrating on-site responder and AED programmes with the local EMS system, and practising and reviewing the response plan (box 1).[28] The plan also should identify the individual(s) responsible for documentation of personnel training, equipment maintenance, actions taken during an emergency and the postevent evaluation of the emergency response.[50]

Personnel

The first person to respond to a medical emergency on the field of play will vary widely and may be a coach, official, student, teammate, teacher, school nurse, certified athletic trainer, physician or other sports medicine professional. All potential rescuers should be familiar with, and ideally trained in, the emergency response plan. Each school, club and organisation should identify a team of rescuers responsible for responding to an SCA. Since sports medicine professionals and healthcare providers are not universally present at all training and sporting activities, coaches and strength and conditioning instructors should receive certified training in CPR and AED use to increase the likelihood a trained rescuer is present in case of an emergency. In US high schools, coaches were found to be the first responder to an SCA in one-third of cases.[20]

General awareness for all staff regarding the emergency plan also is encouraged. While a select response team should be designated and trained in CPR and AED use, all staff should at least be familiar with the location of the AED(s) and the communication system in place to assist in bringing the AED to the victim.

Communication system

An efficient communication network linking all parts of a school or athletic facility, including practice and playing fields, should be developed to enable any first responder to an emergency to activate the EMS system and alert the on-site response team immediately to the emergency and its location. Activation of the internal response team should be simultaneous with activation of the EMS system. The communication network can be developed through existing telephones, cellular telephones, walkie-talkies, alarms, or an intercom or public address system that links a rescuer directly to the EMS or to a central location responsible for contacting the EMS and activating on-site responders. Establishing an accessible communication system will prevent critical delays of a rescuer running from a distant athletic facility or practice field in order to activate the emergency response.

Box 1 Core elements of an emergency response plan for sudden cardiac arrest (SCA)

- Develop a written emergency response plan for SCA.
- Establish an effective and efficient communication system.
- Identify and train likely responders in cardiopulmonary resuscitation and automated external defibrillator (AED) use.
- Access to early defibrillation through on-site AED(s).
- Integrate and register the AED with the local emergency medical services system.
- Practice and review the response plan with potential first responders at least annually.

Location of the AED

A goal of less than 3 to 5 min from collapse-to-shock delivery (time it takes to recognise an emergency, notify designated responders, access the AED, reach the victim, apply the electrodes and deliver the first shock) is recommended.[28 51] If a facility has only one AED, it should be centrally located so it can be brought to the site of SCA through activation of the emergency response plan. Consideration should be given to the most populated areas and proximity to athletic facilities. For large schools and complexes with distant or multiple athletic facilities, duplicate equipment may be needed.

The AED should be highly visible and near a telephone or other means of activating the EMS system and on-site response team. All staff should be instructed on the location of the AED. The AED should be easily accessible during all hours the facility is open, including any sponsored event after usual working hours. The AED should be secured but not placed in a locked box, cabinet or room that is inaccessible at the time of an emergency. Appropriate maintenance and testing of the AED should occur according to the manufacturer's directions and documented. A review of equipment readiness by on-site event personnel for each athletic event is encouraged.

Medical coverage at mass sporting events presents additional challenges to achieving early defibrillation. Distance events such as cross-country meets, triathlons and marathons require careful planning, as race courses are often spread out over long distances and sometimes in remote areas. SCA in marathoners occurs in approximately one in 40 000 runners across the age spectrum.[52] Distributing medical staff and AEDs along the course and using bicycle or ''golf-cart'' rescue teams or emergency vehicles interspersed within the runners will improve response times in the event of an emergency.

Practice and review of the emergency response plan

The emergency plan should be reviewed at least annually with all potential first responders to an SCA; these include certified athletic trainers, coaches, team physicians, athletic training students, strength and conditioning instructors, physical education teachers, school nurses, school and organisational safety personnel, and other sports medicine professionals. In some instances, it may be appropriate to include additional personnel such as administrators, team managers or other school teachers as part of the first response team. More frequent practice sessions will improve the effectiveness, efficiency and organisation of the response, and any modifications to the response plan based on practice drills should be documented.

Integration with the local emergency response system

The emergency response plan should be coordinated with the local EMS system and any on-site AED integrated into the local EMS system. EMS centres should be notified of the specific type of AED and the exact location of the AED. In the event a rescuer is unfamiliar with the facility or where the AED is located, the rescuer can receive instructions from the EMS dispatcher to find and use the AED.[51]

CURRENT RECOMMENDATIONS FOR AEDS IN ATHLETIC MEDICINE

Several US guidelines have provided recommendations for emergency planning for SCA and advocated for the placement of AEDs in the school and athletic setting.[28 50 51 53] In 2002, the 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 emergency equipment and training of involved personnel in CPR and AED use.[50] In 2004, the American Heart Association issued consensus recommendations for the Medical Emergency Response Plan for Schools stating that every school that cannot reliably achieve an EMS call-to-shock interval of less than 5 min should have an AED programme.[51] In 2005, the American College of Cardiology 36th Bethesda Conference suggested that every school that sponsors scholastic sports activities should have access to a defibrillator within 5 min of collapse.[53] And, in 2007, an Inter-Association Task Force represented by 15 national organisations provided consensus recommendations for emergency preparedness for SCA in high school and college athletic programmes, and strongly recommended access to AEDs with a target goal of less than 3 to 5 min from collapse to first shock.[28]

Despite these recommendations, many schools and organisations remain resistant to implementing AED programmes. The primary obstacle to acquiring an AED is financial resources.[27 54 55] While the average cost of an AED ranges from $1500 to $2000, schools and athletic programmes may have limited resources and competing demands on restricted budgets. In Washington State, 60% of high schools with an AED acquired it through donations.[55] While well intentioned, many schools who receive AEDs through donations do not implement the AED as part of a comprehensive emergency response plan for SCA. This can result in limited access or knowledge about the AED on school grounds. Human resources and medicolegal concerns are other potential obstacles to implementing AED programmes.[27 55]

What is already known on this topic

- Sudden cardiac arrest (SCA) is the leading cause of death in exercising young competitive athletes.
- International agreement on the most appropriate cardiovascular screening strategy has not been reached, and most athletes at risk for SCA remain undetected.
- First-responder automated external defibrillator (AED) programmes improve survival from SCA by increasing the likelihood that SCA victims receive bystander cardiopulmonary resuscitation (CPR) and early defibrillation through an organised and practised response.

What this study adds

- All schools, clubs and organisations that sponsor athletic practices and competitions should establish a comprehensive emergency response plan for SCA including training of anticipated first responders in CPR and AED use.
- Access to AEDs with a target goal of less than 3 to 5 min from collapse to first shock is strongly recommended.
- High suspicion of SCA should be maintained in any collapsed and unresponsive athlete with application of an AED as soon as possible for rhythm analysis and defibrillation if indicated.
- AEDs permit early defibrillation not only for young athletes but also for other individuals at a school or athletic venue who experience an unexpected SCA.

On-site AED programmes are likely the only means of consistently and reliably achieving early defibrillation in the athletic setting. Even in communities with advanced EMS systems, the average responses time from call to EMS arrival at the scene may be 6 to 8 min or longer.[56–58] Consensus guidelines and several public access defibrillation studies uniformly support access to early defibrillation targeting a time interval of less than 3 to 5 min from collapse to first shock.[20 27 28 32–39 50 51 53]

SUMMARY AND CONCLUSION

The most important factors influencing survival from SCA are the presence of a trained rescuer to initiate CPR and access to early defibrillation through on-site AEDs. The athletic community is in a unique position to have trained rescuers such as coaches, athletic trainers and sports medicine clinicians respond immediately to SCA at organised practices and competitions. Comprehensive emergency response planning is needed to ensure an efficient and structured response to SCA. This includes establishing a communication system to activate EMS and alert the on-site response team, training of anticipated responders in CPR and AED use, access to an AED, and practice and review of the response plan.

SCA in the athletic setting can be effectively treated through prompt recognition of SCA, a coordinated emergency response, early CPR and defibrillation. Myoclonic activity is common after SCA in young athletes and should not be mistaken for a seizure. High suspicion of SCA should be maintained in any collapsed and unresponsive athlete with application of an AED as soon as possible for rhythm analysis and defibrillation if indicated. Emergency response planning for SCA and prompt availability to AEDs is recommended in all organised athletic settings.

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J A Drezner

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