Sudden cardiac death in athletes

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Exercise is generally a good thing. However, for some it holds hidden danger. The following review discusses the incidence and aetiology of sudden cardiac death (SCD) and measures to reduce the burden of SCD.

Exercise has numerous health benefits, including a lower burden of atherosclerotic risk factors, lower rates of several malignancies and greater lifespan. Regular exercise is recommended by the World Health Organization and several medical governing bodies for prevention of cardiovascular disease.[1]

However, in contrast to the health benefits of exercise there are instances when athletes die suddenly and unexpectedly during exercise from congenital, inherited or acquired cardiovascular disease. In these cases, the stressors of intense exertion – including catecholamine surges, electrolyte derangement, and dehydration – may trigger a fatal cardiac arrhythmia in the setting of an occult structural or electrical abnormality, or silent coronary artery disease (CAD).

Incidence

The incidence of sudden cardiac death (SCD) in athletes ranges from 1:40 000 to 1:250 000,[2–5] and this variation is influenced by the heterogeneity in methodologies, populations and sporting disciplines between studies. Deaths among young athletes (age ≤35 years old) generally occur between the ages of 14 and 30 years and are most common in the second decade of life. Over 80% of SCDs occur during intensive training or competition.

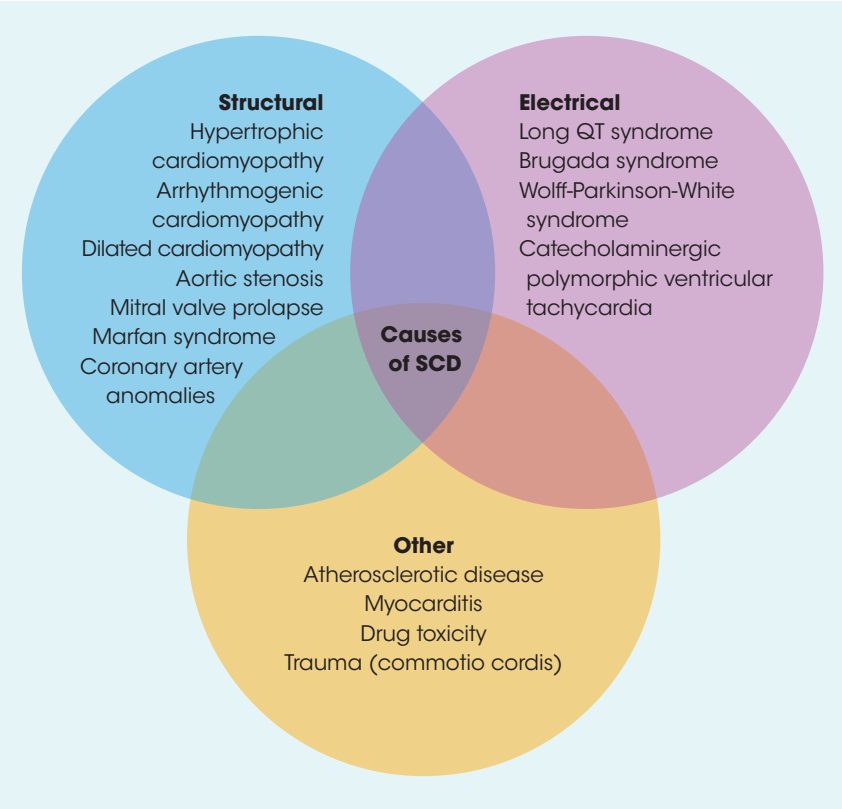


Figure 1. Causes of sudden cardiac death (SCD) in athletes[9]

The largest SCD series in athletes, which consisted of over 1800 deaths, revealed the mean age of death was 19.1 years.[2] Deaths are also significantly more common in males than females,[2,6] with a 9:1 ratio. Data from the USA also suggest that black athletes are more vulnerable to SCD than white athletes.[2,6]

Some sporting disciplines may pose a higher SCD risk. A UK-based study of 11 168 adolescent football players followed up over 10 years reported an incidence of SCD of 1:14 700 (6.8/100 000), which is higher than the average in the UK athlete population.[7] A study of the USA national collegiate athletics association reported that the overall incidence of SCD was 1:53 703, however, the prevalence among male basketball players was 1:52 008.[8] These sports tend to involve intense physical exertion, with a start-stop nature, suggesting that adrenaline surges may trigger fatal arrhythmias.

Aetiology

Cardiovascular disorders account for over three-quarters of non-traumatic sudden death in athletes. SCD in young athletes (<35 years old) is due to a spectrum of structural and electrical disorders with an inherited, congenital or acquired basis (see Figure 1).[9]

Cardiomyopathies represent the commonest cause of inherited structural diseases implicated in SCD. Hypertrophic cardiomyopathy (HCM) is reported as the leading cause of SCD in young athletes in the USA,[10] whereas arrhythmogenic cardiomyopathy (AC) is the leading cause in Italy.[11] The reasons for this difference have been attributed to the mandatory cardiovascular screening programme that is effective for identifying athletes with HCM. Other possibilities include a higher genetic cluster of arrhythmogenic right ventricular cardiomyopathy (ARVC) in Mediterranean populations.

Congenital coronary artery anomalies (CAAs) account for a significant proportion of deaths in young athletes, particularly when the left coronary artery arises from the right sinus of Valsalva and traverses between the aorta and the main pulmonary trunk. Mitral valve prolapse, bicuspid aortic valve and aortopathies are relatively rare causes of SCD in athletes.

Myocarditis has an incidence of 0.5–4% in the general population, but may account for up to 22% of SCD in the young (<35 years).[12] Myocarditis causes myocardial necrosis and fibrosis and, thereby, predisposes to life-threatening ventricular arrhythmias, increasing the risk of SCD. This risk is further exacerbated during exercise. Persistent scar after the acute phase of myocarditis may be a substrate for arrhythmias and increase risk of SCD.

A large UK-based autopsy study at an expert cardiac pathology centre has shown that the heart may be structurally normal in over 40% of cases of SCD (see Figure 2).[13] Our experience of assessing family members suggests that around 50% of SCD cases are due to inherited ion channel diseases such as long QT syndrome, catecholaminergic polymorphic ventricular tachycardia and Brugada syndrome. A small patient population may be due to congenital accessory electrical pathways such as in Wolff-Parkinson-White syndrome. Indeed, a significant proportion of contemporary studies and meta-analyses have shown that a structurally normal heart is a more common finding than cardiomyopathy, resulting in a shift in the paradigm about the aetiology of SCD.[14] Long QT syndrome type 1 is generally implicated in SCD during exercise, especially swimming.

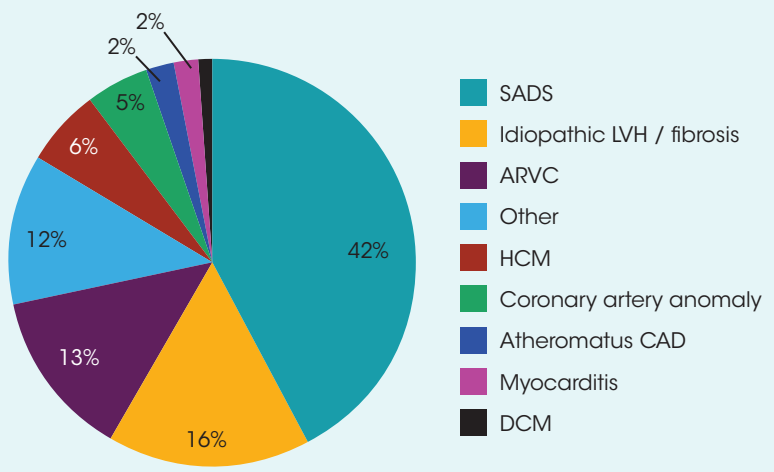
Although most deaths from Brugada syndrome occur at rest, fatal arrhythmias may also occur when the core temperature is >39 degrees Celsius (for example, during prolonged endurance exercise such as marathons or triathlons).

Drug use is also a significant cause of SCD during exercise. Stimulants such as cocaine and amphetamines may increase the risk of myocardial infarction, arrhythmias, myocarditis and premature CAD. Chronic drug use can lead to a dilated cardiomyopathy,[15] and performance-enhancing drugs can have direct adverse effects on the myocardium and vasculature. These agents may allow athletes to push beyond their normal limits, thereby increasing the risk of exercise-induced arrhythmia and SCD;[16] for example, anabolic agents may predispose to dyslipidaemia, hypertension, ventricular hypertrophy and fibrosis, and arrhythmias. Erythropoietin use may increase the risk of myocardial infarction and stroke.[16] Atherosclerotic CAD is by far the most predominant cause in athletes aged over 35 years, and accounts for over 85% of deaths in this cohort.[17] Most SCDs in this cohort occur between the ages of 45 and 55 years.

Screening athletes for cardiovascular disease

Although SCD in athletes is rare it can be diagnosed during life. Furthermore, several therapies, including pharmacotherapy, implantable cardiac defibrillators, cardiac ablation and surgery, are available to modify the natural history of disease and potentially prevent death.

A 25-year nationwide Italian preparticipation screening (PPS) programme[11] involving medical history, examination, 12-lead ECG and limited exercise testing found that 0.2% of athletes had a disorder predisposing to SCD. The false-positive rate was 7% and the use of screening was associated with a reduction in the SCD rate by 90%, from 3.6 per 100 000



Key: ARVC = arrhythmogenic right ventricular cardiomyopathy; CAD = coronary artery disease; DCM = dilated cardiomyopathy; HCM = hypertrophic cardiomyopathy; LVH = left ventricular hypertrophy; SADS = sudden arrhythmic death syndrome

Figure 2. Causes of sudden cardiac death in athletes according to recent pathology study, adapted from Finocchiaro, *et al.*[13]

Box 1. Red flag cardiac symptoms in athletes

- Chest pain or disproportionate shortness of breath on exertion
- Palpitations
- Dizziness or syncope during, or shortly after exertion
- Unexplained or unheralded syncope
- Significant deterioration in athletic performance

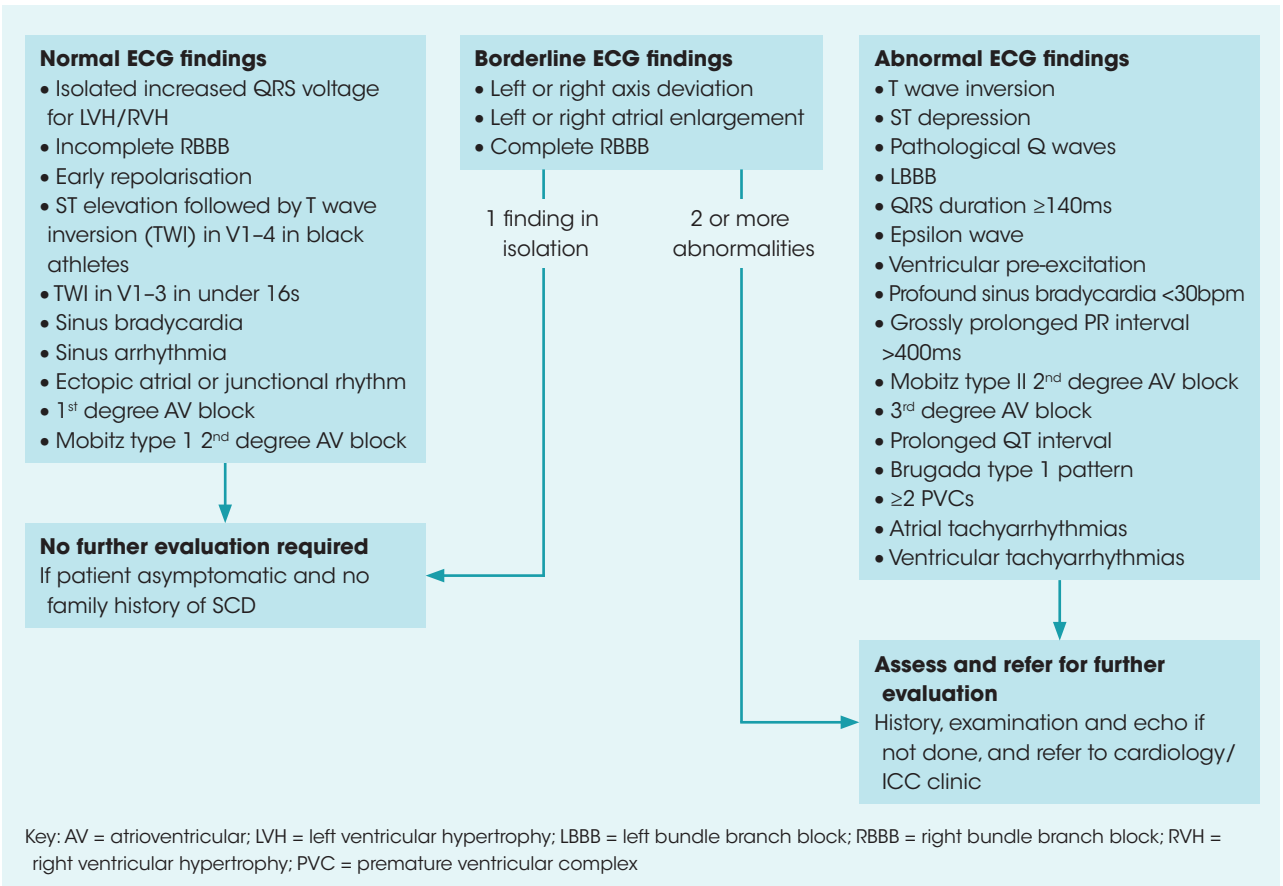
person years to 0.4 per 100 000 person years.

Screening for athletes is currently recommended by the European Society of Cardiology and professional sporting organisations worldwide, including The Football Association and International Olympic Committee,[18] though indiscriminate widespread population-based screening is currently not advocated.

There are two main screening models in use. A low-cost programme has traditionally been used for American high school and college athletes. The programme relies on a heath questionnaire and physical examination. The health questionnaire pertains to potentially serious symptoms (see Box 1) and family history of premature cardiovascular disease. Physical examination focuses on detecting hypertension, coarctation of the aorta, valvular heart disease and Marfan syndrome. This method has poor sensitivity for detecting conditions associated with SCD because most athletes are asymptomatic prior to SCD and physical examination rarely identifies affected athletes.[6,7]

Screening using ECG improves sensitivity through identifying athletes with ion channel disease,[7,11] accessory pathways, and raising suspicion of athletes who may have cardiomyopathy. Over 90% of individuals with HCM and up to 80% of those with AC have an abnormal ECG.

Athletic training is associated with structural changes in the ventricles that may impact on the ECG and overlap with cardiac disease, particularly in athletes of African and African-Caribbean origin, and endurance athletes of all ethnicities.[19] Previous experience has suggested that ECG screening was associated with an unacceptably high false-positive rate of up to 22%, resulting in costly secondary investigations to exclude disease and the potential for erroneous diagnoses and disqualification from



Key: AV = atrioventricular; LVH = left ventricular hypertrophy; LBBB = left bundle branch block; RBBB = right bundle branch block; RVH = right ventricular hypertrophy; PVC = premature ventricular complex

Figure 3. ECG interpretation in athletes (adapted from the International Guidelines for ECG Interpretation in Athletes)[22]

sport.[20,21] Over the past decade, refinement of criteria has culminated in international recommendations for the interpretation of an athlete's ECG (see Figure 3), which have significantly reduced false positive rates to as low as 2.5% in white athletes.[20–22]

It is noteworthy that a resting ECG will not detect incomplete expressions of cardiomyopathy, coronary disease, or adrenergically-mediated arrhythmias in individuals with ion channel diseases. Very detailed investigations to identify these diseases in all athletes are cost prohibitive.

In mature athletes (aged ≥35 years) who have symptoms or risk factors for CAD, an exercise stress test is recommended. Among asymptomatic individuals, 4% will have a positive test of which 95% will not have significant coronary disease.[17]

Eligibility for sports participation

Athletes diagnosed with diseases capable of predisposing them to SCD are advised to abstain from competitive sport of moderate-to-high intensity, although a shared decision-making process between the physician, athletes and (preferably) a club representative is advised.

Contemporary recommendations adopt a liberal approach in some cases of hypertrophic cardiomyopathy and long QT syndrome, although a diagnosis of AC is a contraindication for any exercise exceeding moderate intensity. Individuals with myocarditis should rest for up to six months after initial symptom onset and only be considered for a return to competitive sport if their left ventricular function is normal and there is no evidence of exercise-induced arrhythmias. Asymptomatic individuals with mild valvular heart disease may participate in all sports. A list of recommendations is provided in Table 1.

Emergency care

Despite best efforts to identify those athletes at an increased risk of SCD, not all events can be anticipated.

Condition	Restriction
Myocarditis[23]	• Restriction from all competitive sporting activity during active inflammation and at least 3–6 months from onset of symptoms • Can resume sport after this time provided ECG, echocardiogram, biomarkers of cardiac damage, Holter monitor and exercise ECG are all normal • Should be followed up, especially in first two years
Hypertrophic cardiomyopathy (HCM)[23]	• Participation in sport is contraindicated for those with a history of aborted SCD, unheralded syncope, exercise-induced complex ventricular arrhythmias, a high ESC 5-year risk score, significant LVOTO (>50mmHg) or an abnormal BP response to exercise • Adults with mild clinical expressions of HCM and a low ESC risk score may be permitted to participate in sports after consultation with an expert unless syncope may result in injury
Arrhythmogenic cardiomyopathy (AC)[23]	• Athletes with confirmed or probable AC should avoid all competitive sporting activity except leisure activities of mild-to-moderate intensity
Dilated cardiomyopathy[23]	• Participation in most competitive sport is not recommended • Some asymptomatic individuals with mild LV dysfunction who do not have exercise-induced arrhythmias may continue to participate following discussion with an expert
Aortic stenosis (AS)[24]	• Individuals with mild AS can undertake all sporting activity • Individuals with moderate AS can continue low-intensity sport if functional capacity is adequate and there is no evidence of ischaemia, arrhythmias or abnormal haemodynamic response on a maximal exercise test • Severe AS – avoid competitive sport (except low-intensity activities)
Wolff-Parkinson-White (WPW) syndrome[25]	• Catheter ablation is recommended in all symptomatic individuals and all young (<35 years old) competitive athletes irrespective of symptoms
Long QT syndrome[25]	• Sporting activity can be considered if individuals with mild phenotype (QTc <480ms) who are asymptomatic and treated with a beta-blocker • All other athletes should avoid competitive sport
Brugada syndrome	• Avoid endurance sports such as marathons, triathlons and long-distance competitive cycling
Myocardial infarction (MI)	• Abstain from all intensive exercise for 3–6 months • May return to high-intensity exercise or competitive sport after successful revascularisation if left ventricular function is preserved and there is no evidence of inducible myocardial ischaemia or complex arrhythmias on an exercise test • Conventional post-MI medications and aggressive management of risk factors for atherosclerosis is recommended

Key: BP = blood pressure; ESC = European Society of Cardiology; LV = left ventricular; LVOTO = left ventricular outflow tract obstruction; MI = myocardial infarction; SCD = sudden cardiac death; VT = ventricular tachycardia

Table 1. Restrictions on sporting activity (based on European Society of Cardiology and American Heart Association Recommendations)[23,25]

Effective provision of emergency care at sporting events is essential for preventing death. Emergency planning enables prompt care, with an emphasis on early recognition of cardiac arrest, cardiopulmonary resuscitation and early defibrillation.[26]

Considerations include formulating an emergency action plan, training medical personnel, and provision of sufficient automated external defibrillators (AEDs) at appropriate locations. These can be altered to match requirements of the sport, event type, number and age of participants, and location. For example, a stadium event will present different logistical challenges to a marathon spread over a wide area.

AEDs should be placed so that any athlete suffering sudden cardiac arrest (SCA) can receive defibrillation within three minutes.[26] The use of AEDs can increase survival after cardiac arrest by up to 64%, and schools and sporting locations with on-site AED programmes have a high survival rate from SCA.[27,28] Targeted training in resuscitation for families of those at high risk of SCD is also feasible, but there is currently insufficient evidence of benefit in reducing the risk of SCD.[29]

Conclusion

Sudden death in athletes is an uncommon but catastrophic event. Most cases are attributable to cardiac conditions and are rarely preceded by symptoms. Screening athletes with an ECG has an important role in identifying silent abnormalities; however, several diseases are not detectable, particularly in mature athletes. As a result, the availability of an automatic external defibrillator, coupled with an effective emergency response plan, is important to reduce the risk of SCD in athletes.

Declaration of interests: *none declared.*

Key points

- Sudden cardiac death (SCD) in sport is a rare but catastrophic event, with an incidence of approximately 1 in 50 000
- Among young athletes (<35 years old), deaths are most commonly due to a diverse spectrum of inherited and congenital abnormalities, including cardiomyopathy, coronary anomalies and ion channel diseases
- Coronary artery disease (CAD) is the most common cause of death in middle aged and older athletes (>35 years)
- There is a strong male predisposition for SCD in athletes of all ages
- Most athletes are asymptomatic prior to SCD
- ECG screening is effective for identifying athletes with serious electrical diseases and raising suspicion of those with cardiomyopathy
- The ECG may be normal in CAD and incomplete expressions of cardiomyopathy
- Early cardiopulmonary resuscitation and application of an automatic external defibrillator improves survival by a four-fold increase

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