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Sudden Cardiac Death in Athletes: Risk Factors, Screening and Prevention

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Abstract

Background: Sudden cardiac death (SCD) in athletes is rare, but it remains an important problem because it may occur unexpectedly in individuals with no previously recognized cardiovascular disease. Its causes differ with age and include cardiomyopathies, coronary artery abnormalities, myocarditis, coronary artery disease and primary electrical disorders.

Aim: To summarize current evidence on the epidemiology, causes, risk factors and warning signs of SCD in athletes, and to discuss cardiovascular screening, prevention, emergency management and return to sport.

Materials and methods: A narrative review was conducted using PubMed, Web of Science and Google Scholar. English-language full-text studies published between 2015 and 2026 were considered, including original studies, systematic reviews, meta-analyses and narrative reviews.

Results: SCD is uncommon, but its incidence varies between athlete populations and is higher in males. In younger athletes, cardiomyopathies, coronary artery anomalies and primary electrical disorders are important causes, while coronary artery disease becomes more relevant with age. ECG screening may improve the detection of cardiovascular conditions associated with SCD, although its effect on mortality remains uncertain. Early CPR and rapid AED use are consistently associated with better survival after sports-related cardiac arrest.

Conclusions: Prevention should combine cardiovascular assessment with awareness of warning symptoms and effective emergency preparedness. Return-to-sport decisions should be individualized according to the underlying cardiovascular condition and follow-up findings.

Keywords: sudden cardiac death; sudden cardiac arrest; athletes; cardiovascular screening; electrocardiography; cardiopulmonary resuscitation

1. Introduction

1.1. Definition and epidemiology of sudden cardiac death in athletes

Sudden cardiac death (SCD) is defined as an unexpected death resulting from a cardiac cause, usually occurring within a short period after the onset of symptoms in an individual without a formerly recognized fatal condition. It should be distinguished from sudden cardiac arrest (SCA), which refers to the abrupt cessation of effective cardiac activity but does not necessarily result in death if circulation is successfully restored. In athletes, these events attract particular attention because they often occur in individuals who are young, physically active and perceived as healthy. Although SCD during sport is uncommon, its unanticipated nature and

potentially preventable causes make it an important issue in sports medicine and preventive cardiology [1,7].

Reported estimates of SCA and SCD in athletes vary considerably between studies, largely because of differences in population characteristics, definitions, and case-identification methods. Overall, these events are rare, although risk varies across athletic populations and appears to change with factors such as sex, age, type of sport, and level of competition [8,9,14,15].

SCD can occur through different levels of sports participation, including recreational activity. Its underlying risk profile also changes with age, with inherited or congenital cardiovascular disorders playing a greater role in younger athletes and coronary artery disease becoming increasingly relevant in older individuals [7,23].

1.2. Pathophysiological background and clinical significance

Frequent physical activity has well-established cardiovascular benefits and should not itself be considered a cause of SCD. However, intense exercise can act as a trigger in individuals with a pre-existing structural, electrical or acquired cardiac disorder. During vigorous exercise, increased sympathetic activity and greater cardiac workload may facilitate ventricular arrhythmias in susceptible athletes [1,7].

This relationship is particularly relevant in conditions such as cardiomyopathies and myocarditis, where exercise may increase arrhythmic risk and, in some cases, contribute to disease progression [11,20]. The effect of physical exertion therefore depends largely on the underlying cardiovascular substrate rather than exercise alone.

The clinical importance of SCD goes beyond its low incidence. In some athletes, cardiac arrest may be the first sign of previously unrecognized disease, while other conditions can potentially be detected before a serious event occurs. This creates a difficult balance in sports medicine: most athletes are healthy, and their absolute risk is low, but missing a clinically important cardiovascular disorder may have severe consequences. Identifying athletes who require further evaluation therefore remains an important part of prevention [1,2,7].

1.3. Major causes of sudden cardiac death in athletes

Sudden cardiac death in athletes may originate from several different cardiovascular conditions, and the most common causes are not the same in every age group. In younger athletes, cardiomyopathies, congenital abnormalities of the coronary arteries and primary electrical disorders are among the main conditions associated with SCD. In older athletes, coronary artery disease becomes increasingly important [7,9,23].

Myocarditis and arrhythmogenic cardiomyopathy also need to be considered, particularly because both may increase the risk of ventricular arrhythmias during exercise [11,20]. In some cases, however, no clear structural abnormality is found after death. This may partly reflect underlying electrical disorders that cannot be identified during routine post-mortem examination [8,9]. The wide range of possible causes makes it difficult to identify all athletes who may be at increased risk.

1.4. Aim of the study

This narrative review aims to summarize current evidence on sudden cardiac death in athletes, with emphasis on epidemiology, major cardiovascular causes, risk factors, and clinical warning signs. Additionally, the review evaluates the role of cardiovascular screening in identifying athletes at increased risk, discusses available strategies for prevention and emergency management of sudden cardiac arrest in sports settings, and outlines current considerations regarding return to sport following cardiac events.

2. Research methods

This narrative review was based on a literature search conducted in PubMed, Web of Science and Google Scholar. The archives of *Quality in Sport* and the *Journal of Education, Health and Sport* were also searched for relevant publications. The search focused on studies published between 2015 and 2026. The final literature search was completed on August 5, 2026.

The primary search strategy combined terms associated with sudden cardiac events and sports participation: ("sudden cardiac death" OR "sudden cardiac arrest" OR "cardiac arrest") AND (athlete* OR sport* OR "young athlete*"). The search syntax was adapted as required for individual databases and journal search engines. Additional searches were conducted to identify publications relevant to specific topics discussed in the review, including

cardiovascular causes and risk factors, screening, prevention, emergency management, and return to sport.

English-language, full-text publications involving human subjects were considered when they were relevant to sudden cardiac arrest or sudden cardiac death in athletes. Original studies, systematic reviews, meta-analyses and narrative reviews were included. Papers that did not focus on athletic or sports-related populations or were not directly related to the aims of the review were excluded.

3. Results

3.1. Epidemiology and characteristics of sudden cardiac death in athletes

The reported incidence of sudden cardiac arrest and sudden cardiac death in athletes varies considerably between studies, reflecting differences in study populations, age limits, athlete definitions, case identification methods, and inclusion of both survived and fatal events. A systematic review and meta-analysis by Lear et al. found that studies with low risk of bias generally reported an incidence below 2 cases per 100,000 athlete-years. In regional or national populations including athletes of various levels, the pooled incidence of SCD was 0.98 per 100,000 athlete-years, while among competitive athletes aged 14–25 years, it was 1.91 per 100,000 athlete-years [14]. These findings confirm that SCD is uncommon, but also demonstrate that incidence estimates depend strongly on the population studied.

Risk is not distributed equally among athletes. In a large analysis of NCAA athletes, SCD was the most common medical cause of death and occurred more frequently in men than in women. Black athletes also had a higher observed incidence than white athletes, and the highest-risk subgroup was represented by male Division I basketball players [8]. A subsequent prospective US study confirmed substantial differences according to sex, level of competition and sport. In that cohort, African American male Division I basketball players had the highest reported risk, with an incidence of approximately one event per 2,087 athlete-years [9]. More recent pooled analyses showed similar differences. Li et al. reported an incidence of SCA and SCD of 1.42 per 100,000 athlete-years in male athletes compared with 0.32 per 100,000 athlete-years in female athletes [15]. Taken together, the available evidence consistently shows a clear male predominance, although the magnitude of the difference varies between populations and sporting disciplines.

The type of sport and setting in which exercise is performed additionally influence the observed characteristics of SCA. In a prospective study of 132 exercise-related cardiac arrests in young competitive athletes, 84% of affected individuals were male. Basketball accounted for 30% of cases, followed by American football at 25%, while track or cross-country running and soccer represented smaller proportions [5]. Importantly, sports-related cardiac arrest is not restricted to elite or competitive athletes. A population-based study of adults aged 18–35 years in Germany and France found that most events occurred in recreational male participants rather than organized competitive athletes [6]. This is consistent with newer evidence showing that cardiovascular events during sport also affect amateur populations, in whom structured preparticipation assessment may be less common [23].

Endurance events provide another useful perspective on the epidemiology of sports-related cardiac arrest. An earlier systematic review of marathon running reported SCD estimates ranging from approximately 0.6 to 1.9 per 100,000 participants, with most events occurring in men and the mean age of affected runners generally being between the late thirties and late forties [12]. More recent data from US marathons and half-marathons identified 176 cardiac arrests among more than 29 million race finishers between 2010 and 2023. Although participation increased substantially, the incidence of cardiac arrest remained relatively stable compared with earlier observations, while the incidence of fatal cardiac arrest and case fatality decreased [10]. Thus, contemporary evidence suggests that the absolute risk during endurance events remains low despite the very large number of participants.

3.2. Major cardiovascular causes and risk factors

The underlying causes of SCD differ substantially with age. In younger athletes, inherited structural heart disease, congenital abnormalities and primary electrical disorders account for a large proportion of events, whereas atherosclerotic coronary artery disease becomes increasingly important with advancing age [1,2,7]. This age-related pattern is also observed outside elite sport. Among amateur and recreational athletes, hypertrophic cardiomyopathy, coronary artery disease and myocarditis are repeatedly identified among the relevant underlying conditions, with traditional cardiovascular risk factors becoming more important in older participants [23].

Cardiomyopathies remain a major group of disorders associated with SCA and SCD in younger athletes. In the prospective US surveillance study by Peterson et al., hypertrophic

cardiomyopathy was the most frequently identified diagnosis, accounting for 20.6% of cases in which an etiology was established. Idiopathic left ventricular hypertrophy accounted for 13.4%, coronary artery anomalies for 12.0%, and autopsy-negative sudden unexplained death for 9.6% [9]. Earlier NCAA data also presented considerable heterogeneity of underlying disease and showed that a definitive structural diagnosis cannot be established in every case [8]. The presence of autopsy-negative SCD is clinically important because it raises the possibility of primary electrical disorders, including channelopathies, in which the heart may appear structurally normal. Disorders such as long QT syndrome, Brugada syndrome and catecholaminergic polymorphic ventricular tachycardia may therefore remain undetected unless appropriate clinical, electrocardiographic or genetic evaluation is performed [7].

Arrhythmogenic cardiomyopathy represents another particularly relevant cause of exercise-related SCD. Long-term data from an Italian referral centre showed that ACM accounted for 29% of sudden deaths among young competitive athletes included in the registry. The incidence of ACM-related SCD decreased over time, from 0.43 per 100,000 athletes per year before 2010 to 0.14 per 100,000 athletes per year thereafter. The study also documented a wider phenotypic spectrum than the historically described predominantly right ventricular disease, with increasing recognition of left ventricular involvement [11]. This evidence is relevant because exercise can interact with the underlying arrhythmogenic substrate in ACM and may contribute to the occurrence of ventricular arrhythmias in susceptible athletes.

Congenital coronary artery abnormalities are another established cause of SCD, particularly in younger athletes. An anomalous aortic origin of a coronary artery may compromise coronary blood flow during intense exercise via several mechanisms related to the abnormal origin and proximal course of the vessel. Clinically significant anomalies may therefore result in exercise-induced myocardial ischemia and ventricular arrhythmias despite an otherwise normal cardiac examination [21]. The importance of coronary pathology is not limited to congenital abnormalities. In the population-based study of sports-related SCA in adults aged 18–35 years, coronary artery disease was the most commonly identified cause [6]. Similarly, in the recent analysis of cardiac arrests during US marathons and half-marathons, coronary artery disease was more common than hypertrophic cardiomyopathy among cases in which a definitive etiology could be determined [10]. These observations show that coronary disease can contribute to sports-related cardiac arrest even before the age traditionally associated with veteran athletes.

Myocarditis represents an acquired substrate for potentially malignant arrhythmias. Myocardial inflammation may result in myocyte injury and electrical instability during the acute phase, while residual myocardial scar can remain arrhythmogenic after apparent clinical recovery [20]. Reviews of SCD in athletic populations estimate that myocarditis accounts for a smaller but clinically relevant proportion of sudden deaths and note that a fatal arrhythmia may occasionally be the first manifestation of the disease [2]. The relationship between vigorous physical exercise and active myocardial inflammation is particularly important because exercise increases adrenergic stimulation and cardiac workload at a time when the myocardium may already be electrically unstable [20].

Several non-disease characteristics are repeatedly associated with higher observed rates of SCA and SCD. Male sex is one of the most consistent findings across cohorts and meta-analyses [8,15]. Age changes the dominant underlying pathology, while type and intensity of sporting activity also influence risk. In amateur athletes, reported factors include male sex, intense exertion, smoking, hypertension, dyslipidemia, previous myocardial infarction, coronary stenosis and a family history of premature coronary disease [23]. The potential contribution of drugs or performance-related substances has also been examined. In a multinational post-mortem study including 3,189 cases of SCD, 219 of which were sports-related, sports-related deaths that occurred predominantly in younger men. They were frequently associated with structural cardiac disease. Although positive toxicological findings were present in a proportion of cases, drugs specifically considered to be associated with SCD were uncommon [16]. Consequently, available evidence supports underlying cardiovascular disease as the dominant substrate in most sports-related SCD rather than toxicological exposure alone.

3.3. Clinical presentation and warning signs

Identifying symptoms before a cardiac event remains difficult because SCA or SCD may be the first manifestation of previously unrecognized cardiovascular disease. Many young athletes with potentially lethal cardiac conditions have no previous symptoms, and normal athletic performance does not exclude clinically relevant pathology [5,7]. Nevertheless, several symptoms should raise suspicion, particularly when they appear during or immediately after intense exercise. Exertional chest pain or pressure, unexplained syncope or presyncope, palpitations, disproportionate dyspnea, dizziness and an unexplained reduction in exercise tolerance are among the most important warning features described in athlete assessment [1,2]. A family history of premature sudden death, cardiomyopathy, channelopathy or unexplained

cardiac arrest further increases concern and ought to prompt more detailed cardiovascular evaluation [1,2].

The diagnostic value of symptoms differs between individual diseases. Coronary artery anomalies illustrate this limitation particularly well. In one series of young persons with SCD caused by anomalous coronary origin, approximately half had previously reported symptoms such as chest pain, syncope or dyspnea. In another cohort of athletes who died because of an anomalous aortic origin of a coronary artery, only 37% had experienced preceding cardiac symptoms [21]. Moreover, exercise testing may fail to demonstrate ischemia even in individuals who subsequently experience SCD. In the US prospective surveillance study, coronary artery anomalies were especially relevant in younger athletes, and exertional chest pain or syncope were identified as symptoms that should lead to investigation for anomalous coronary anatomy [9]. Thus, the presence of exercise-related symptoms is clinically meaningful, but their absence cannot consistently exclude a potentially dangerous coronary anomaly.

Acquired disease may produce a different clinical pattern. Myocarditis can follow a viral or other inflammatory illness and may present with chest discomfort, dyspnea, palpitations, arrhythmias or an unexplained deterioration in exercise capacity. However, manifestations can be mild or nonspecific, and ventricular arrhythmia or cardiac arrest may occasionally occur without a prolonged symptomatic phase [20]. For this reason, recent systemic illness accompanied by new cardiovascular symptoms should be regarded as significant for an athlete. Physical examination may also provide warning signs, including a pathological cardiac murmur, irregular rhythm, or elevated blood pressure, while features suggesting inherited connective tissue or cardiovascular disease may justify further investigation [2]. Overall, history and symptoms remain important tools for identifying athletes who require additional evaluation, but the literature consistently shows that symptom-based assessment alone will not identify all individuals at risk of SCA or SCD.

3.4. Cardiovascular screening of athletes

Cardiovascular preparticipation screening is intended to identify athletes with previously unrecognized conditions associated with an increased risk of sudden cardiac arrest or death. Most screening strategies begin with a personal and family history and physical examination, with further testing guided by abnormal findings. The main area of disagreement concerns the

routine inclusion of a resting 12-lead electrocardiogram (ECG). European screening models generally support the ECG use in young competitive athletes, whereas approaches in the United States have traditionally relied more on history and physical examination, with ECG added selectively [1–3]. The challenge is detecting disease adequately without generating an excessive number of false-positive findings in a predominantly healthy population.

Available evidence shows that adding ECG improves the detection of cardiovascular abnormalities associated with SCD. In a meta-analysis including 28,011 athletes aged 10–35 years, 124 cardiac diagnoses were identified, of which 103 were conditions associated with SCD. The association between ECG screening and detection of both cardiac disease and SCD-associated conditions was substantially stronger than that observed for history and physical examination alone [17]. However, improved diagnostic yield does not automatically demonstrate a reduction in mortality. A separate systematic review and meta-analysis including four non-randomized studies and more than 11 million participants found very low-quality evidence regarding the effect of ECG screening on SCD. The pooled analysis suggested a relative risk of 0.58, but the confidence interval was wide and included the possibility of both benefit and harm (95% CI 0.23–1.45) [18].

Long-term data from structured screening programmes provide additional information. In the Italian programme studied by Sarto et al., 22,324 children underwent 65,397 cardiovascular evaluations over 11 years. Screening included history, physical examination, resting ECG and exercise testing, with additional investigations performed when required. Cardiovascular conditions associated with an increased risk of SCD were diagnosed in 69 athletes (0.3%). Importantly, 44 of these diagnoses were made during repeat evaluations rather than during the initial assessment, showing that a single screening examination may miss diseases that develop or become phenotypically apparent later [2]. During a mean follow-up of 7.5 years, one athlete with previously normal screening findings experienced a resuscitated cardiac arrest during exercise.

The interpretation of an athlete's ECG is itself an important part of the screening process. Training-related cardiac adaptation can produce findings such as sinus bradycardia, increased QRS voltage or early repolarization, which should not automatically be interpreted as pathological. Modern athlete-specific interpretation criteria were developed to reduce unnecessary investigations whilst maintaining the ability to recognize abnormalities suggestive of cardiomyopathy or electrical disease [3,24]. A recent systematic review also emphasized

that ECG patterns are influenced by age, sex and type of sport, supporting the need to interpret findings within the individual athlete's clinical and training context [24].

The problem of false-positive findings is particularly relevant in younger athletes. In a Swiss multicentre study of 891 athletes younger than 18 years, 19 individuals (2.1%) had an ECG considered abnormal according to contemporary interpretation criteria and required further investigation. No relevant cardiovascular pathology was eventually identified in these athletes, and all were cleared for competition with follow-up. The total screening cost was approximately USD 108,860, corresponding to USD 122 per athlete [19]. These data illustrate that even relatively specific ECG criteria may lead to additional diagnostic testing and costs in populations where serious cardiovascular disease is uncommon.

Additional investigations, including echocardiography, exercise testing, ambulatory ECG monitoring, cardiac magnetic resonance imaging and genetic testing, are generally used when initial assessment raises suspicion of cardiovascular disease rather than as universal first-line tests [1,2]. New technologies may broaden the possibilities for cardiac monitoring outside the clinical setting. A scoping review of wearable and portable devices identified 35 studies evaluating cardiac signal acquisition during sport, including devices recording heart rate and, in some cases, ECG signals. However, substantial differences in device performance and validation protocols were observed, and the authors emphasized the need for standardized validation before these technologies can be incorporated more reliably into clinical practice [22]. At present, wearable devices therefore appear more appropriate as complementary monitoring tools than as replacements for established cardiovascular screening methods.

3.5. Prevention and emergency management

Prevention of sudden cardiac death in sport goes beyond identifying athletes at risk before participation. No screening strategy is capable of detecting every potentially fatal cardiac condition, and some athletes who experience SCA have previously undergone normal cardiovascular evaluation. For this reason, preparedness for an unexpected cardiac arrest remains an essential part of prevention. Recommended measures include a clearly defined emergency action plan, rapid recognition of SCA, immediate activation of emergency medical services, early cardiopulmonary resuscitation and rapid access to an automated external defibrillator [4]. Training coaches, medical personnel and other individuals regularly present

at sporting venues in CPR and AED use is therefore an important component of emergency preparedness.

The association between early basic life support and survival is particularly strong in sports-related SCA. Michelland et al. included 28 non-randomized studies in a systematic review and meta-analysis and found that bystander presence was associated with greater survival (OR 2.55; 95% CI 1.48–4.37). The association was stronger when bystander CPR was performed (OR 3.84; 95% CI 2.36–6.25), while bystander AED use showed the strongest association with survival (OR 5.25; 95% CI 3.58–7.70) [13]. These results support a rapid sequence of recognition, CPR and defibrillation rather than reliance on the arrival of professional emergency services before treatment is initiated.

Observational records from athletic populations show similar findings. In the prospective study by Drezner et al., 93% of exercise-related cardiac arrests in young competitive athletes were witnessed. Overall survival was 48%, but it increased to 83% when a certified athletic trainer was present and involved in the resuscitation and to 89% when an on-site AED was used [5]. In another population-based study of sports-related SCA among adults aged 18–35 years, bystander CPR was provided in more than 80% of cases, whereas an AED was used before arrival of emergency medical services in only a small minority. Public AED use was independently associated with survival, and 10 of 11 individuals who received both immediate bystander CPR and early AED defibrillation survived to hospital discharge [6].

This information shows that prevention operates at two levels. Cardiovascular assessment seeks to reduce the number of events by identifying high-risk disease before competition, while emergency preparation aims to improve survival when prevention is unsuccessful. The availability of a functional AED at sporting facilities, a rehearsed emergency action plan, and personnel trained to administer immediate CPR therefore complement cardiovascular screening rather than replace it [4,13].

3.6. Return to sport after cardiac events

Return to sport following the diagnosis of cardiovascular disease or recovery from a cardiac event cannot be based on a single universal protocol. The decision depends on the underlying condition, its treatment, residual ventricular dysfunction or arrhythmic risk, the intensity of the intended sport and the results of follow-up evaluation. In practice, return-to-sport assessment

ranges from temporary exercise restriction followed by reassessment to permanent avoidance of high-intensity competitive activity in selected high-risk disorders [7,20,21].

Myocarditis is an important example of a condition requiring temporary withdrawal from intensive exercise. Athletes with active myocardial inflammation are considered to be at increased risk of ventricular arrhythmias, and sports participation should be suspended during the active phase. The literature included in this review describes a period of exercise restriction followed by reassessment after approximately 3–6 months. Return to training should be considered only after clinical recovery, normalization of ventricular function and biomarkers, and the absence of clinically relevant arrhythmias on appropriate follow-up testing [20]. The process should be gradual, particularly when myocardial injury or scar has previously been demonstrated.

Return-to-sport decisions may be more complex in congenital or inherited disorders because the underlying anatomical or genetic substrate may remain present despite treatment. In athletes with anomalous aortic origin of a coronary artery, the approach depends strongly on coronary anatomy, symptoms and evidence of inducible ischemia. An anomalous left coronary artery with a high-risk interarterial course generally requires restriction from competitive sport until surgical correction. In contrast, an asymptomatic athlete with an anomalous right coronary artery, no high-risk anatomical features and no evidence of inducible ischemia may be considered for continued participation after detailed evaluation, counselling and follow-up [21]. This illustrates the increasing role of individualized risk assessment and shared decision-making rather than applying identical restrictions to every athlete with the same diagnostic label.

Overall, return-to-sport decisions should be based on the underlying cardiovascular condition and follow-up assessment results. The available evidence also supports an individualized approach, particularly when risk cannot be clearly determined [20,21]. Long-term follow-up remains important in athletes with cardiovascular disease that may persist or progress over time. The presence of previous cardiac arrest, ventricular arrhythmias, exercise-related symptoms, significant structural disease or persistent abnormalities on follow-up testing generally requires a more guarded approach [7,11]. Regardless of the underlying diagnosis, the decision to resume competitive activity must follow review of the athlete's current cardiovascular status rather than simply the passage of a predetermined period. Long-term

follow-up remains important because several diseases associated with SCD may progress or become clinically apparent over time.

4. Discussion

4.1. Interpretation of the main findings

The findings of this review confirm that sudden cardiac death in athletes is a rare event, but its occurrence is not evenly distributed across the athletic population. Reported incidence varies considerably between studies, partly because of differences in case definitions, study populations and methods of event identification [1,14]. Despite these methodological differences, several patterns remain consistent. Male athletes are affected much more often than females, and the risk appears to be higher in selected sports and competitive groups [8,9,15]. This suggests that SCD risk should not be considered uniform and that age, sex, type of sport and level of competition may all be relevant when assessing an individual athlete.

Another important finding is the marked heterogeneity of the underlying cardiovascular diseases. No single condition explains the majority of cases across all populations. Cardiomyopathies, coronary artery abnormalities, myocarditis and primary electrical disorders are particularly important in younger athletes, while coronary artery disease becomes increasingly relevant with age [1,7,9,20,21,23]. Even within similar age groups, reported distributions of causes differ between countries and registries. In addition, a proportion of sudden deaths remain unexplained after autopsy, which may reflect primary electrical disease that cannot be identified by routine post-mortem examination [1,8,9]. These differences make a universal approach to risk prediction difficult and help explain why no single screening test can identify every athlete who will later experience SCA or SCD.

Taken together, the evidence supports a wider view of prevention. The aim should not be to identify one dominant cause of SCD, but rather to recognize athletes with clinical features that justify further assessment while accepting that some events will remain unpredictable. This is especially important because SCA may be the first manifestation of previously undiagnosed cardiovascular disease.

4.2. The role and limitations of cardiovascular screening

Cardiovascular screening remains one of the most debated aspects of SCD prevention in athletes. There is broad agreement that personal and family history, together with physical examination, play an important role in preparticipation assessment, but the routine use of ECG remains controversial [1–3]. The main argument in favour of ECG is its capacity to detect electrical abnormalities and signs of cardiomyopathy that may not produce symptoms or abnormal findings on physical examination. Meta-analytical evidence indicates that adding ECG improves the detection of cardiovascular conditions associated with SCD compared with history and physical examination alone [17].

However, better detection of cardiovascular abnormalities should not automatically be interpreted as proof that ECG screening reduces mortality. Lear et al. found that the available studies assessing the effect of ECG screening on SCD were non-randomized, had a high risk of bias and provided very low-quality evidence. Although the pooled estimate suggested a possible reduction in SCD, the uncertainty was substantial, and a clear mortality benefit could not be established [18]. This distinction matters: screening can identify more disease without necessarily showing that population-wide screening prevents enough deaths to justify a single universal strategy.

False-positive results represent another limitation. Physiological cardiac adaptation to training can resemble pathological changes, particularly on ECG, and unnecessary referral may lead to additional imaging, temporary restriction from sport, anxiety and increased costs. Modern interpretation criteria have reduced this problem, but have not eliminated it [3,19]. Moreover, ECG patterns differ by age, sex, and sporting discipline, making appropriate interpretation dependent on experience with athletic populations [24]. This evidence favours screening performed within structured programmes with access to clinicians familiar with sports cardiology, rather than isolated testing without an established pathway for further evaluation.

For these reasons, cardiovascular screening should be viewed as a tool for risk reduction rather than a guarantee against SCD. A more individualized strategy, taking into account symptoms, family history, age, sport and other risk factors, may provide a reasonable balance between early detection and unnecessary investigation [1,2]. At present, the evidence supports the diagnostic value of ECG, but remains insufficient to resolve the debate over mandatory universal ECG screening.

4.3. Prevention of sudden cardiac death in sports

The limitations of screening point up the importance of secondary prevention. Even a well-designed preparticipation programme will not identify every athlete at risk, and therefore sporting environments must also be prepared for cardiac arrest when it occurs [4]. This is particularly relevant because exercise-related SCA is often witnessed, creating a short but important window for immediate intervention. In the study by Drezner et al., survival was substantially higher when a certified athletic trainer participated in resuscitation and when an on-site AED was used [5].

Evidence from larger analyses supports the same conclusion. The meta-analysis by Michelland et al. provided a strong association between basic life support measures and survival after sports-related SCA, with bystander CPR and particularly early AED use associated with better outcomes [13]. Similar findings were reported in young adults experiencing sports-related SCA, where rapid bystander response and early defibrillation were among the main determinants of survival [6]. These observations suggest that improving emergency response may have a more immediate effect on survival than attempts to eliminate every possible cardiac event through screening alone.

Effective prevention should therefore combine both approaches. Preparticipation assessment aims to identify athletes with clinically relevant cardiovascular disease before an event occurs, whereas emergency action plans, CPR training and immediate access to AEDs provide protection when prediction fails [4,5,13]. The two strategies should be regarded as complementary rather than competing methods of reducing the consequences of SCD in sport.

4.4. Clinical and practical implications

The findings of this review have practical implications not only for sports cardiologists, but also for primary care physicians, coaches and organizations responsible for sporting events. Cardiovascular prevention should combine appropriate preparticipation assessment with awareness of warning symptoms and access to further diagnostic testing when abnormalities are identified [2]. At the same time, screening alone cannot eliminate SCA risk. Sporting facilities should therefore have a clear emergency action plan, personnel trained in cardiopulmonary resuscitation and rapid access to an AED [4,13]. This approach is relevant not only to competitive athletes, but also to amateur and recreational participants, who may have cardiovascular risk factors despite having no previous structured cardiac assessment [23].

4.5. Future perspectives

Future research has to focus on improving risk stratification and identifying which athletes benefit most from additional cardiovascular testing. Further refinement of athlete-specific ECG interpretation may help maintain diagnostic sensitivity while decreasing unnecessary investigations [24]. Repeated assessment may also be important because some cardiovascular disorders become clinically apparent only with age or disease progression [2]. Wearable and portable technologies offer an additional opportunity for monitoring cardiac signals during exercise, but their clinical role remains unclear because available devices differ considerably in accuracy and validation [22]. Better prospective studies, standardized registries and longer follow-up will be necessary to determine how these tools can be incorporated into efficient prevention strategies.

5. Limitations

Several limitations should be considered when interpreting this review's findings. As this was a narrative review, the literature was selected based on its relevance to the topics discussed rather than through a formal systematic review process. The included studies also differed in their definitions of sudden cardiac arrest and sudden cardiac death, athlete populations, age groups, screening strategies and methods of event identification, which makes direct comparison between studies difficult. In addition, much of the available evidence comes from observational studies and registries. Findings from young competitive athletes may therefore not always be directly applicable to amateur or recreational populations.

6. Conclusions

Sudden cardiac death is uncommon in athletes, but it is still a serious problem because it can affect individuals who appear healthy and have no formerly recognized cardiovascular disease. Given the diversity of underlying causes, no single screening method can identify every athlete at risk. Prevention should therefore integrate comprehensive cardiovascular assessment, awareness of warning symptoms, and robust emergency preparedness. In the event of sudden cardiac arrest, early CPR and rapid use of an AED can substantially be associated with improved survival. Athletes with known cardiovascular disease should undergo individualized assessment before resuming training or competition.

Supplementary Materials

Not applicable.

Author Contributions

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Aleksandra Kinga Łysak - investigation, resources, writing

Jakub Gałwiazek - resources, writing, rough preparation

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Conflicts of Interest

The authors declare no conflict of interest in relation to this study.

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