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Sudden Death in Sports: Modern Concepts

Regular physical activity provides significant health benefits and reduces the risk of premature death from any cause, including cardiovascular diseases (CVD). However, physical activity may provoke sudden cardiac death (SCD), especially in presence of unrecognized diseases. It is essential to identify risk factors that contribute to SCD in athletes and to implement effective prevention of such episodes. For this purpose, SCD registries are being created, medical terminology is being unified, and schedules of medical examination are being developed. The best strategy to combat SCD during sport activities is a combination of primary prevention by screening examination to identify athletes with CVD at risk and a proper planning of first aid measures during sports events, including the availability of an automatic external defibrillator on site.

Keywords Sudden death; sudden cardiac arrest; sport

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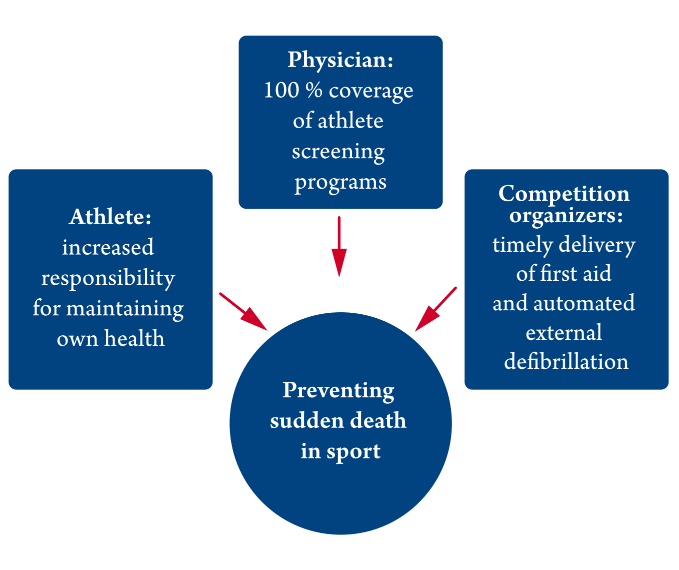
Introduction

There is strong evidence that regular physical activity has a significant health benefit and reduces the risk of premature all-cause death, including cardiovascular death [1, 2]. However, physical activity can cause sudden cardiac death (SCD), especially in the presence of an undiagnosed condition [3]. Episodes of ventricular tachycardia or ventricular fibrillation underlie SCD, resulting in sudden arrest of the systemic and cerebral circulation [4].

The amount of physical activity plays an important role in this condition. Nearly 4 in 10 Europeans say they exercise at least once a week. However, 13% of Europeans do not walk for at least 10 consecutive minutes a week and 11% spend more than 8.5 hours a day sitting [5]. In the context of the promotion of healthy lifestyles and sports, a certain part of the population is changing its lifestyle and turning to amateur or professional sports rather late in life. At the same time, population studies show that the survival curve has an inverted J-shape with maximum mortality at both sedentary lifestyle and high-intensity physical activity, especially in insufficiently physically trained individuals [6] (Figure 1, adapted from [6]).

The curve of the coronary complication incidence, which depends on the intensity and amount of physical activity per week, has the same J-shape [7, 8]. Relative coronary insufficiency under conditions of intensive and prolonged cardiac work, especially when the heart is hypertrophied, and the development of fibrosis, electrolyte and degenerative changes in the myocardium serving as a substrate for arrhythmias are considered to be the main causes of SCD.

Central Illustration. Sudden Death in Sports: Modern Concepts



These events may be due to the hemodynamic stress induced by exercise and the release of catecholamines, which increase the probability of acute ischemia, myocardial infarction and SCD by 6–16 times during and within 1 hour after exercise compared to the resting state [9]. In this context, it is important to identify risk factors for SCD in athletes and to implement effective prevention of such episodes. To this end, registries of SCD are being established, terminology is being standardized, and medical examination schemes are being developed.

Definitions

Several consensus-approved concepts are used in the registration of death [10–12].

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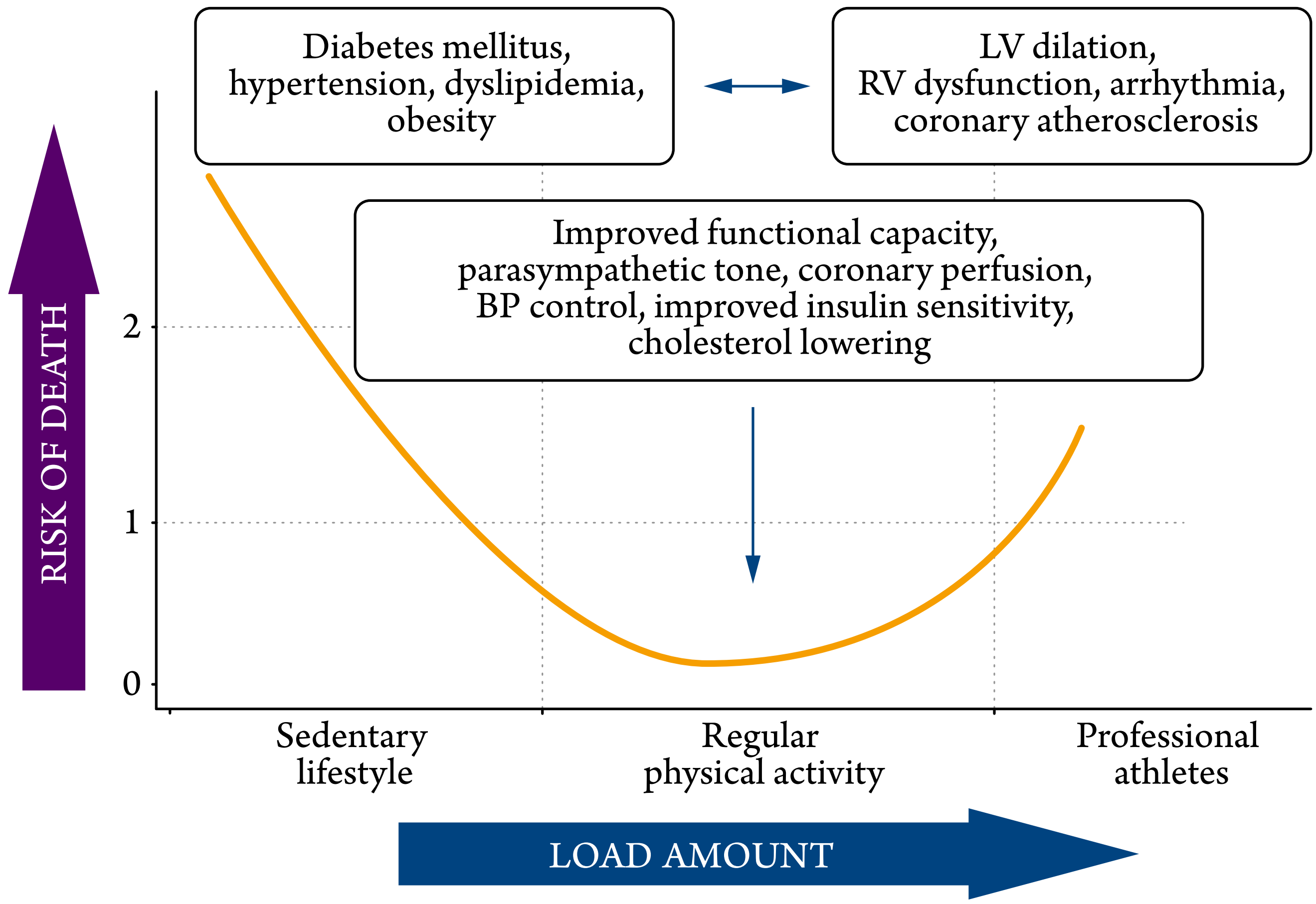
Figure 1. Relationship between level of load and factors that influence health and mortality



LV, left ventricle; RV, right ventricle; BP, blood pressure.

Sudden unexplained death (syndrome) is a death occurring in a person older than 1 year of age who was last seen alive and functioning normally less than 24 hours before being found dead and is witnessed as an acute change in cardiovascular status with time to death <1 hour.

Sudden arrhythmic death (syndrome) is an unexplained sudden death occurring in a person with a negative pathological and toxicological evaluation. It is synonymous with autopsy-negative death.

Exercise-related sudden death is an unexpected death that occurs during or immediately after exercise (1–3 hours) from any cause other than violence. The event may be further characterized as occurring during exercise or competition, at rest, or during sleep.

When the death is suspected to be related to cardiac disease, the following qualifiers are used.

Sudden cardiac arrest (SCA) is an unexpected circulatory arrest of cardiac origin that was reversed by successful resuscitation and/or defibrillation, regardless of subsequent survival.

Sudden cardiac death (SCD) is a term used in the following cases:

- The deceased had congenital or acquired potentially life-threatening heart disease during life;
- Autopsy reveals a cardiac or vascular disease that could be the cause of sudden death;
- Autopsy reveals no other non-cardiac cause of death and suggests that death may have been caused by arrhythmia (autopsy-negative death).

Epidemiology of sudden cardiac arrest / sudden death

By 2021, it is well established that the overall incidence of SCD ranges from 15 to 159 cases per 100,000 person-years, representing 6–20% of all deaths [11], and depends on the region and the principles of death registration. For example, the incidence per 100,000 person-years is 34.4 cases in Europe, 53.1 in North America, 59.4 in Asia, and 49.7 in Australia. At the same time, the survival rate is extremely low in cases of hospitalization: 7.6%, 6.8%, 3.0%, and 9.7%, respectively [13].

The incidence of SCA/SCD in the general population, as reported in the literature, is higher than in athletes. However, when events unrelated to systematic physical activity are excluded, the incidence of SCD is 2.5–4.5 times higher in athletes than in comparable populations [14, 15]. At the same time, even with this approach, there is still considerable variation in the published incidence of SCA/SCD in sports [16]. The maximum incidence is 1.33/50,000 person-years and the minimum is 1/917,000 person-years. Among high school athletes: 1/46,000–1/917,000, among college athletes 1/43,000–1/83,000 person-years. Results published after 2003 suggest a range of 0.47–6.75 cases per 100,000 person-years in professional sports and 0.12–1.7 cases in recreational sports [17].

Obviously, intensive sports loads can act as a trigger for SCD. At the same time, SCD in sports has a high public resonance, attracting more attention than incidents in the general population.

Unfortunately, there is no register of SCD in sports in the Russian Federation, so it is not possible to study this problem in depth and find ways to solve it in Russia. In Russian literature, the majority of sudden deaths are diagnosed as autopsy-negative death [18], while in foreign literature, this diagnosis is found in 22–42% of cases [19–21].

Causes of sudden cardiac arrest/sudden death

Since there is no disease that causes SCD in 100% of cases, other factors associated with an increased risk of sudden death have gradually been identified. These include male sex, older age, certain ethnic origins, and participation in certain sports.

In different age groups, the causes of death vary because of differences in the diseases that predominate in each group. In this regard, the following age groups are distinguished: young athlete – an individual between 12 and 35 years of age, senior athlete – an individual over 35 years of age. In young people, SCD is most often caused by hereditary heart diseases, including primary arrhythmogenic diseases (e.g., congenital long QT syndrome and catecholaminergic polymorphic ventricular tachycardia), various types of cardiomyopathies (hypertrophic, arrhythmogenic, dilated). Hereditary heart disease may remain a common cause of SCD until at least 50 years of age. However, after the age of 35, the role of the leading cause of SCD shifts to coronary artery disease (CAD). Moreover, coronary artery abnormalities, aortic dissection, congenital heart disease, and myocarditis can occur at any age. Non-ischemic scarring of the left ventricular myocardium may be a not uncommon clinically occult substrate for life-threatening arrhythmias in the athlete [22]. Such myocardial damage can be caused by various diseases, including myocarditis, sarcoidosis, and genetic cardiomyopathy. The incidence of SCD is relatively low in children and young adults under the age of 35 but increases dramatically in the 60–80 age group.

It should be noted that the age limit of 35 years is rather conventional. Thus, CAD was recognized as the main cause of SCA in young athletes (younger than 35 years) with cardiac arrest (not death) based on a relatively large number of coronarograms (62.5%) in one of the studies [23] (Table 1, adapted from [23]).

Table 1. Causes of sudden cardiac arrest among athletes 18–35 years of age

Disease	Frequency among those who experienced SCA, %
Coronary artery disease	25.8
Idiopathic ventricular fibrillation	13.5
Myocarditis	11.2
Hypertrophic cardiomyopathy	7.9
Sudden arrhythmic death syndrome	6.7
Arrhythmogenic cardiomyopathy	5.6
Dilated cardiomyopathy	5.6
Congenital coronary artery abnormality	5.6
Brugada syndrome	2.2
Sarcoidosis	2.2
Other known diseases: - 3rd degree AV block; - Idiopathic left ventricular hypertrophy; - Mitral valve prolapse; - Myocardial bridges; - Takotsubo cardiopathy; - WPW syndrome; - Aortic dissection	1.1% on average

AV, atrioventricular block; WPW syndrome, Wolff-Parkinson-White syndrome.

In Germany and France, a total of 147 cases of SCA in athletes were reported over 7 years, corresponding to 4.77 (95% CI: 2.85–6.68) cases per 1 million population per year (0.5/100,000). Most cases have been reported in amateur rather than professional athletes. The underlying mechanism was an acute coronary syndrome with a clearly identifiable lesion, suggesting that the exertion induced by physical activity could cause atherosclerotic plaque disruption due to increased vessel wall stress.

Similar findings were reported by Karam et al [24], who showed that the angiographic pattern of CAD in both sports-related and non-sports-related SCA was unexpectedly similar in terms of the presence of chronic occlusions and multivessel disease. In addition, the majority of athletes had symptoms prior to SCA. Despite this, the athletes remained physically active and only 50% sought emergency medical care prior to SCA, highlighting the lack of awareness of CAD symptoms.

SCA can occur in any sport, but these cases are more frequently reported in mass sports, probably due to the larger number of participants [23, 24]. For example, the most common physical activities for health

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improvement in Europe are swimming (22%), cycling (19%), walking (14%), running (13%), and football (6%) [25]. However, three of these sports, cycling (28%), football (18%), and running (17%), are the leading sports in terms of the incidence of SCA/SCD in athletes [26]. It should be noted that in the Swedish population, golf (24.9%) and group exercise in fitness centers (23.9%) are also considered to be high-risk sports [27].

Sudden death screening options

There is a tremendous amount of research conducted on SCD. SCD has been found to have a cardiac origin in approximately 80% of patients with SCD who are brought to the emergency department and are considered to be resuscitable [28]. At the same time, pre-screening can reduce mortality in athletes by 89% [29]. To date, pre-screening to identify individuals with CVDs at risk of SCD has been recommended by the American Heart Association (AHA), the European Society of Cardiology (ESC), the International Olympic Committee, and most medical associations and sports federations worldwide [21, 30, 31]. In Russia, the Ministry of Health regulates the examination requirements and scope for sports admission through its Order No. 1144n dated 23.10.2020 [32]. The Guidelines for the Admission to Sport of Individuals with Cardiovascular Diseases and Abnormalities have recently been revised and are also used [33, 34].

It is important to acknowledge that screening volumes and patterns vary significantly between countries. This is based on a different interpretation of the potential risks and the high cost of the examination. To reduce the cost of screening, some countries, such as the USA, UK, and Spain, recommend conducting screening without recording an electrocardiogram (ECG) and, of course, without echocardiography [35–39]. The most comprehensive examinations are conducted in Norway, Germany, and France, as well as in Russia. [40]. Load tests are mandatory in Germany and France. FIFA and UEFA are two of the most responsible sports associations.

While ECG improves diagnosis to some extent, it does not reflect most structural changes in the heart. Therefore, echocardiography is a must for the evaluation of coronary artery abnormalities, localized myocardial hypokinesia, valvular or ventricular dysfunction. If needed, a more comprehensive examination is conducted during the second stage of diagnosis.

Preventing SCD is a complex issue that cannot be solved by cardiovascular screening alone. It involves three main components:

1. Detecting structural or electrical abnormalities of the heart during annual screening;
2. Identifying risk factors for SCA for each disease;
3. Establishing a structure for emergency field care for SCA.

Effectiveness of sudden cardiac arrest/sudden death screening

Currently, screening diagnosis has been developed to identify specific phenotypes for almost all known types of pathology that may result in SCA. These phenotypes can be established by clinical signs, using ECG or echocardiography. According to Italian authors, screening can detect conditions potentially associated with SCA, which allows prescribing specific treatment in about 0.4% of patients [17]. The positive test result (risk of death) has a prognostic value of 4.7% with a sensitivity of 25%.

The generally accepted screening protocol (case history, physical examination, baseline ECG, echocardiogram, and exercise testing) provides good sensitivity to detect the most common conditions associated with the risk of cardiac arrest/sudden death, such as cardiomyopathy, canalopathy, WPW syndrome, mitral valve prolapse. However, advanced imaging studies (cardiac MRI and CT coronary angiography) or invasive tests (electrophysiologic testing and endomyocardial biopsy) are required for less common causes such as nonischemic left ventricular scarring, CAD, congenital coronary abnormalities, acute myocarditis, and idiopathic ventricular fibrillation.

It is important to note that the presence of changes in the cardiovascular system, sometimes very pronounced, does not prevent many athletes from achieving the highest results. According to Pelliccia et al. [41, 42], Olympic athletes, despite the absence of symptoms and their outstanding athletic performance, are not immune to the development of CVDs, and 3.9% of them have heart pathology with an unexpectedly high risk of lethal outcomes during sports. The situation is even worse for Paralympic athletes. Among Italian athletes who have achieved recognition in international competitions, including world championships, and have been selected as candidates for the Paralympic Games, 9% were found to have dangerous structural heart diseases and 3% had various types of tachyarrhythmia. Diseases that are either absent at the time of screening or have no clear phenotype are of even greater concern.

Can cardiovascular problems be clinically silent in high-performance athletes?

Up to two-thirds of CVDs at risk for SCD are diagnosed during annual screening, mainly genetic cardiomyopathy with late phenotypic expression or recently acquired myocardial disease [43]. However, the aggregate sensitivity of conventional screening is not as high as desired. Repeated examinations can somewhat increase the efficacy of screening. For example, Sarto et al [44] found that the diagnostic efficacy of each stage of screening was 0.12% at the first examination and 0.1% at the repeated examination. Therefore, the indicator is 0.05% for children aged 7 to 11 years and 0.12% for children aged 12 to 18 years. During a follow-up period of 7.5 ± 3.7 years, one athlete with normal initial screening results experienced cardiac arrest and required resuscitation during sports activities.

It is important to note that some CVDs, such as CAD and congenital coronary artery abnormality, may not present symptoms for extended periods of time and may not cause abnormalities in ECG. Therefore, it is important to assess the cumulative risk of CVDs in older athletes and, if deemed high, conduct exercise testing and/or CT coronary angiography [12]. However, according to studies, increased risk is found during screening only in 57.8% of individuals who later develop SCA [24]. Moreover, the effectiveness of screening of professional athletes before competition decreases as the complexity of diagnostic tests increases. Genetic analysis can provide additional information, but it is generally expensive and only indicated in the presence of a clear disease phenotype.

Other circumstances can also decrease the effectiveness of screening. Besides structural pathology, critical conditions may be caused by various idiopathic arrhythmias that are not detectable during screening but may occur later, such as acute myocarditis. It is impossible to predict the development of commotio cordis, a life-threatening arrhythmia usually caused by blunt trauma to the chest wall, which until recently has been a significant cause of SCD in the United States [45]. This circle also includes other cases of autopsy-negative cardiac deaths in athletes that have been consistently reported [19–21].

Cardiovascular diseases and risk of sudden cardiac arrest/sudden death

Determining whether or not this particular pathology will lead to SCA in this particular athlete is a major problem. For example, the prevalence of hypertrophic cardiomyopathy (HCM) in the population is 1/500 and the maximum incidence of SCA is 0.5%. This means that about 2,000 people out of a million examined will be excluded from sports, but 99% of them will never experience SCA [46]. In this regard, an important area of research is the substantiation of criteria and variants of an unfavorable course of HCM, such as the presence of intraventricular obstruction or syncope, which would be an absolute contraindication to sports activities. Similar considerations apply to other cardiomyopathies and disorders of cardiac electrical activity.

In their summary paper, Stormholt et al. [47] showed that alarming symptoms may include dyspnea, syncope (at rest or during exercise), dizziness, palpitations, blurred vision, chest pain/angina, and palpitations, which occur in 14–74% of athletes before the onset of SCD. Such significant differences in symptom incidence among publications highlight the importance of thorough history-taking for targeted medical evaluation.

Emergency field care for sudden cardiac arrest

SCA and SCD are not diseases and therefore cannot be detected in advance. As a result, no single screening strategy can identify all athletes at risk for SCA/SCD. As noted above, cardiac pathology may arise and latently progress between two in-depth medical examinations, may develop as a result of dangerous doping and drug abuse, and may also go undetected by special examination methods. Elements of uncertainty are created by individuals with borderline changes in cardiac structure and ECG, which may not develop into dangerous conditions throughout a person's life or, on the contrary, may suddenly manifest themselves in an ordinary situation (such as uncomplicated myocardial bridges, mitral valve prolapse, bicuspid aortic valve, benign coronary artery abnormality, etc.) [35]. These circumstances dictate the need for appropriate medical infrastructure to provide emergency care in the field, especially the use of automated external defibrillators (AEDs) and the careful development of emergency plans. Using defibrillation within 3–5 minutes of the onset of cardiac arrest is the most important determinant of survival in SCA [48].

To date, favorable results of this approach have been reported in many countries. As immediate cardiopulmonary resuscitation is more frequently performed in athletes (85.7–90.3% of cases) than in the general population (60.9%; $p<0.001$) [48, 49], the survival rate for SCA is 3–8 times higher in athletes [20, 50, 51]. According to recent reports, it reaches 85–90% after victims are brought to the hospital [21, 23]. For this reason, the terms "sudden death" and "cardiac arrest" are no longer considered interchangeable in athletes, as the latter can be successfully treated.

Conclusion

Therefore, the best strategy to manage sudden cardiac death in sports is a combination of primary prevention through screening to identify athletes at risk for cardiovascular disease and the availability of on-site defibrillators to provide life-saving defibrillation in the event of unpredictable cardiac arrhythmias. Increasing the number of personnel trained in CPR (including athletes themselves, sports officials, emergency responders,

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police, security personnel, and volunteers) and developing and coordinating emergency response plans can further reduce mortality from sudden cardiac arrest, especially among athletes. Efforts to reduce the incidence of sudden cardiac death will be improved by monitoring the impact of different interventions in this area.

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