REVIEW ARTICLE

Sudden Cardiac Arrest in Athletes

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SUMMARY

The incidence of sudden cardiac arrest in athletes varies according to age, race and ethnic group, sex, sport, and social determinants of health. The common causes of sudden cardiac arrest include cardiomyopathies, electrical disorders, coronary-artery anomalies, and other cardiac structural abnormalities. There has not been an increase in the incidence of sudden cardiac arrest in athletes during the time frame of the coronavirus disease 2019 (Covid-19) pandemic. Primary prevention is based on cardiovascular screening before participation, and secondary prevention on implementation of emergency action plans. Diagnostic evaluation of athletes who survive sudden cardiac arrest should mirror that of age-matched nonathletes, with additional sport-specific considerations, and should be performed by medical professionals with expertise in the interpretation of test results in the context of athletic adaptation. An increasing body of evidence indicates that many athletes can return to play after disease-specific treatment, without an increase in risk, and professional societies now consider return to participation in sports to be reasonable or appropriate through shared decision making for numerous cardiac conditions.

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The death of an athlete at any age is shocking and incongruent with our perception of athletes as members of the healthiest segment of society. Exercise and fitness are keys to health and longevity. An understanding of the incidence and causes of sudden cardiac arrest and death in athletes guides strategies for prevention — both primary prevention by means of screening before participation in sports and secondary prevention with the use of emergency action plans. Many athletes who have survived sudden cardiac arrest hope to return to their sport. In the past, professional society recommendation statements restricted a return to play for athletes after sudden cardiac arrest; however, more recent statements emphasize the importance of shared decision making and management strategies geared toward facilitating a return while minimizing risk through appropriate disease-specific therapeutic interventions, when possible.

INCIDENCE

The reported incidence of sudden cardiac arrest and death in athletes varies, depending on how “athlete” is defined and how accurately and inclusively cases are identified.[1] Some studies rely on mandatory reporting, some rely on media reports, and others use data from registries or from death certificates or insurance claims. Incidence estimates also depend on how precisely the population at risk is defined with respect to age, sex, race or ethnic group, and sport. Some studies include data on sudden cardiac arrest in athletes who survive; others include only data on fatal cardiac arrests. Finally, some studies include events that occurred at any time,

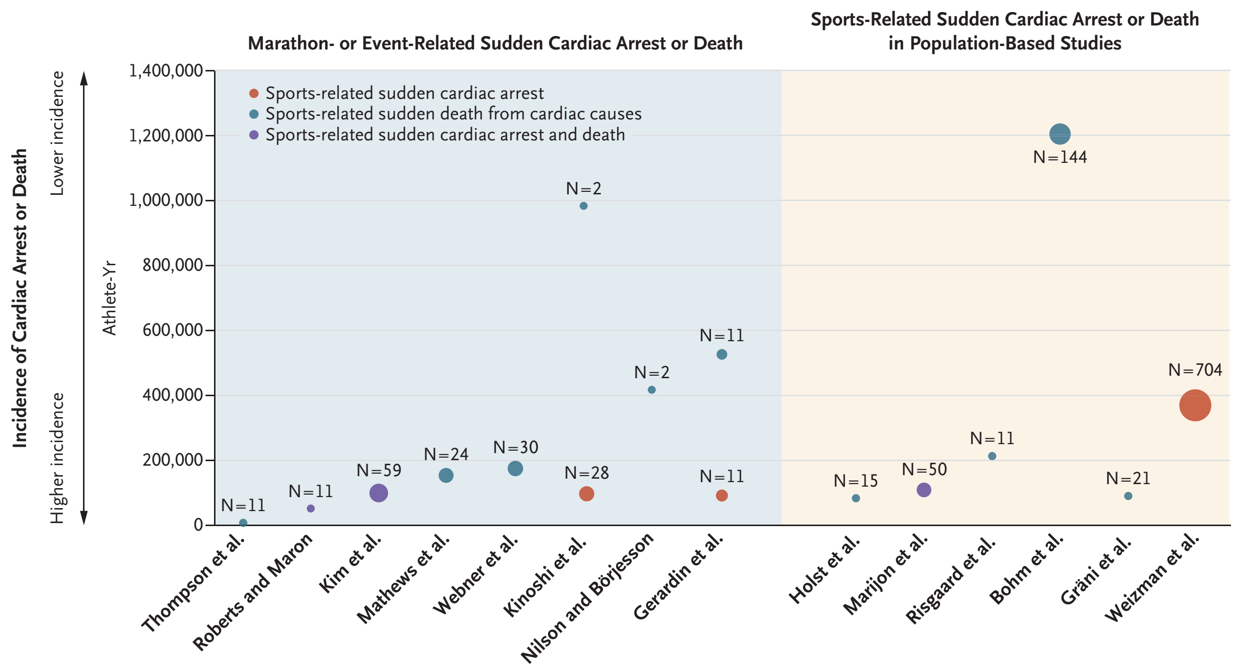

Figure 1. Incidence of Sports-Related Sudden Cardiac Arrest or Death.

The y axis shows the incidence of sudden cardiac arrest or sudden death from cardiac causes as 1 case in 200,000 to 1,400,000 athlete-years, with the highest incidence shown at the bottom of the axis. Numbers of cases reported in studies by Bohm et al.,[2] Gerardin et al.,[3] Gräni et al.,[4] Holst et al.,[5] Kim et al.,[6] Kinoshi et al.,[7] Marijon et al.,[8] Mathews et al.,[9] Nilson and Börjesson,[10] Risgaard et al.,[11] Roberts and Maron,[12] Thompson et al.,[13] Webner et al.,[14] and Weizman et al.[15] are shown, with larger circles indicating higher numbers of cases. The incidence from the study by Weizman et al. (largest circle) includes data from men only.

whereas other studies include only those that occurred during or within an hour after exercise, termed sports-related sudden cardiac arrest and death (Fig. 1, and Table S1 in the Supplementary Appendix, available with the full text of this article at NEJM.org).

For this review, we define an athlete as a person who is engaged in habitual and vigorous training for the purposes of obtaining a high level of fitness.[16,17] This definition includes competitive athletes and high-level recreational athletes.

AGE-SPECIFIC INCIDENCE

Athletes are generally divided into the following age groups: prepubertal (which corresponds approximately to ≤12 years), adolescent (approximately 13 to 17 years), young adult (approximately 18 to 24 years), adult (approximately 25 to 34 years), and masters (≥35 years). The one study that evaluated the incidence of sudden death from cardiac causes among prepubertal athletes showed a rate of 1 death in 500,000 athlete-years.[18] In a study involving athletes who were 7 to 18 years of age, one athlete was resuscitated from sudden cardiac arrest, for a rate of 1 death in 167,000 athlete-years.[19] Almost all children are active, and the population-based incidence of sudden cardiac arrest and death in this age group appears to be similar to the incidence among young athletes.[20]

In the adolescent age group (13 to 17 years), the overall incidence of sudden cardiac arrest and death is reported to be 1 case in 66,000 to 88,000 athlete-years, with a higher incidence in specific populations, such as elite male soccer players (1 in 14,794 athlete-years) and male basketball players (1 in 21,000 athlete-years).[21-25] The incidence among young adult or college-age athletes is slightly higher than the incidence among adolescent athletes, a finding that may represent either an elevated risk or more robust case ascertainment. Studies of college athletes, which benefit from precise denominators for participating athletes, have shown an incidence of 1 case in 51,000 to 67,000 athlete-years.[24,26,27] The incidence of sudden cardiac arrest and death specifically in adult athletes (25 to 34 years of age) or masters athletes (≥35 years of age) has not been reported. Denominators for the number of athletes per age group are difficult to ascertain, and data come from studies that span large age groups or from studies of sports-related sudden cardiac arrest and death. Population-based data on the incidence of sudden death from cardiac causes show a sharp increase beginning at the age of 25 years, which reflects a greater prevalence of coronary disease among adults than among younger persons.[16] Studies of sports-related sudden cardiac arrest and death are typically either retrospective population-based studies that attempt to identify which decedents were athletes[2,4,5,8,11,15] or studies of deaths related to marathons or other athletic events that include older athletes (Fig. 1).[3,6,7,9,10,12-14]

INCIDENCE ACCORDING TO SEX AND RACE OR ETHNIC GROUP

Male athletes have a higher risk of sudden cardiac arrest and death than female athletes, with 1 case in 35,000 to 83,000 athlete-years among male athletes as compared with 1 case in 93,000 to 323,000 athlete-years among female athletes.[21-25,28,29] Two robust studies have examined the incidence of sudden cardiac arrest and death according to race or ethnic group.[24,27] In a study of data over a 4-year period that included both fatal and nonfatal sudden cardiac arrest in college athletes, the incidence among Black athletes was 1 event in 18,000 athlete-years, as compared with 1 in 39,000 athlete-years among White athletes.[24] In a study of National Collegiate Athletic Association (NCAA) athletes, which examined only sudden deaths from cardiac causes that occurred over a period of 20 years, the incidence was 1 death among 27,000 Black athletes, as compared with 1 death among 75,000 White athletes.[27] The extent to which these disparities are based on differences in disease prevalence as opposed to social determinants of health has not yet been established. The prevalence of conditions associated with sudden cardiac arrest and death is believed to be similar among Black athletes and White athletes; however, contemporary data are lacking.[30] Among high-school athletes, the outcomes after sudden cardiac arrest are worse for athletes who are members of underrepresented racial and ethnic groups than for non-Hispanic White athletes (survival, 51% vs. 76%) and are also worse for athletes with lower socioeconomic status than for those with higher socioeconomic status.[31]

SPORT-SPECIFIC INCIDENCE

In studies that examined risk according to the sport, the incidence of sudden cardiac arrest and death was highest in men's basketball, soccer, tackle football, ice hockey, and cross-country running,[23,24,27] with a higher risk in basketball than in other sports even after adjustment for race and sex.[27] Data from a review of sudden deaths from cardiac causes in the NCAA suggested that the incidence was higher in Division I than in lower divisions[32]; however, a recent update shows no difference.[27] Previous differences may have been due to differences in reporting. How sport, race or ethnic group, sex, and social determinants of health interact to influence the incidence of sudden death from cardiac causes is an important area for future investigation.

CARDIAC CAUSES OF SUDDEN DEATH IN ATHLETES

The causes of sudden cardiac arrest and death in athletes are also difficult to reliably ascertain because of a lack of standardization in the performance of autopsies and the assessment of findings, with heterogeneity in pathological definitions, histopathological evaluations, use of genetic testing, and the participation of a specialized cardiac pathologist. In addition, not all autopsy-based studies include toxicology screens, and the contribution of performance-enhancing drugs to sudden death from cardiac causes has not been extensively studied. Although pinpointing the relative contributions of specific causes is difficult, an understanding of the differential diagnosis guides the evaluation of athletes who survive sudden cardiac arrest, as well as that of family members of athletes who have died.

Causes of death, like incidence, show age-associated patterns. In athletes younger than 25 years of age, the primary causes of sudden cardiac arrest and death are congenital, electrical, and structural diseases. Acquired cardiac conditions,

Study	Country	Type of Cardiac Arrest or Death	Population	Age Range yr	No. of Cases	HCM %	Idiopathic LVH, Fibrosis, or Cardiomyopathy NOS %	Coronary-Artery Anomalies %	Arrhythmogenic Cardiomyopathy %	DCM %	AN-SUD %	CAD %	Myocarditis-Related %	Aortic Dissection %	Commotio Cordis %	Other %
Corrado et al.	Italy	SDC	Competitive athletes	12–35	46	2	0	13	26	2	2	22	11	2		20
Harmon et al.	U.S.	SDC	High-school athletes	14–18	50	14	26	8	2	0	18	6	14	0	0	12
Thiene et al.	Italy	SDC	Athletes	<40	75	5	0	16	27	0	11	23	4	0	0	15
Egger et al.	Many	SCA/D	Recreational, competitive, and elite soccer players	≤35	104	11	9	13	4	1		14	13	0	7	36
Peterson et al.	U.S.	SCA/D	Athletes	11–29	209	21	13	12	6	3	19	2	4	3	0	16
Finocchiaro et al.	U.K.	SDC	Athletes	18–35	128	3	12	9	8	3	52	1	0	0	5	7
Bohm et al.	Germany, France	EA-SCA/D	Recreational and competitive athletes	18–35	25	8	4	0	0	4	24	20	16	0	0	24
Petek et al.	U.S.	SDC	Competitive athletes	18–26	118	13	17	8	5	2	19	6	7	4	2	17
Total					**755**	**12**	**11**	**10**	**8**	**2**	**20**	**8**	**6**	**1**	**2**	**20**

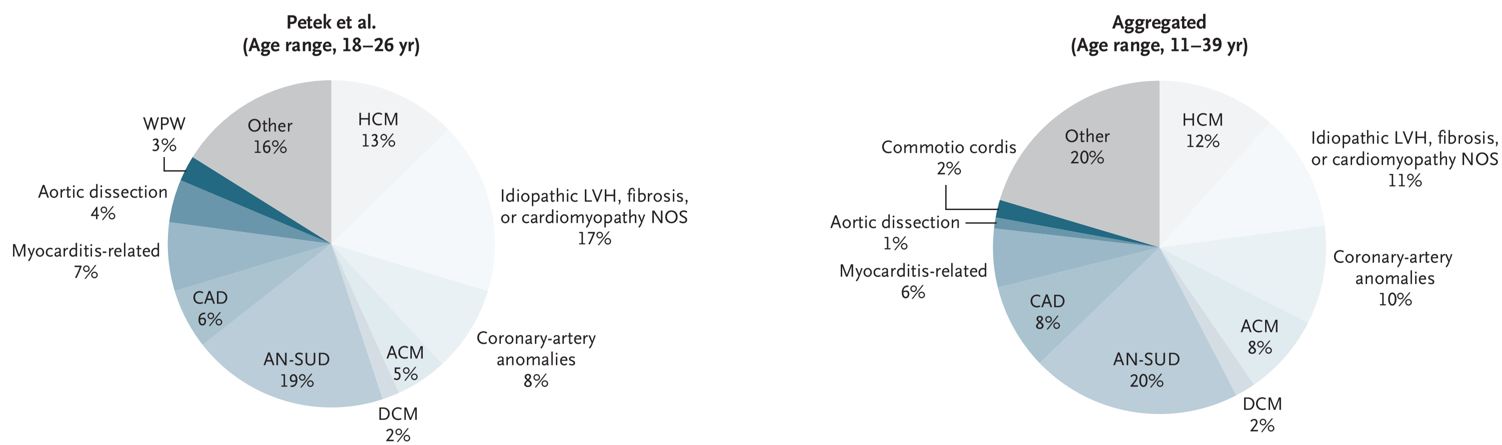

Figure 2. Cardiac Causes of Sudden Death in Athletes.

Only data from studies that included autopsy-negative, sudden, unexplained death (AN-SUD) among possible causes are shown. Data are from Bohm et al.,[36] Corrado et al.,[28] Egger et al.,[37] Finocchiaro et al.,[33] Harmon et al.,[22] Petek et al.,[27] Peterson et al.,[24] and Thiene et al.[38] ACM denotes arrhythmogenic cardiomyopathy, CAD coronary artery disease, DCM dilated cardiomyopathy, EA-SCA/D exercise-associated sudden cardiac arrest or death, HCM hypertrophic cardiomyopathy, LVH left ventricular hypertrophy, NOS not otherwise specified, SCA/D sudden cardiac arrest or death, SDC sudden death from cardiac causes, and WPW the Wolff–Parkinson–White syndrome.

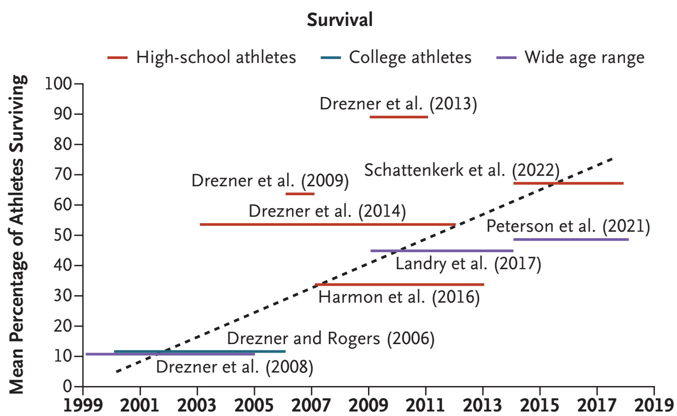

Figure 3. Survival after Sudden Cardiac Arrest in Young, Competitive Athletes in North America.

The horizontal lines represent the time frame of the studies. Data are from Drezner and Rogers,[50] Drezner et al.,[21,51-53] Harmon et al.,[22] Landry et al.,[54] Peterson et al.,[24] and Schattenkerk et al.[31] The dashed line provides a visual representation of the trajectory.

particularly coronary artery disease, become increasingly prevalent with age and account for the majority of deaths among athletes 25 years of age or older.[16] In contemporary studies involving athletes 11 to 40 years of age, sudden death from cardiac causes with a pathologically normal heart on autopsy — autopsy-negative, sudden, unexplained death — is the most common finding, which suggests that arrhythmia due to diseases that affect the electrical system, such as channelopathies, is the cause of death.[27,33] Previous studies suggested that hypertrophic cardiomyopathy was the leading cause of death. However, these findings may have been affected by referral bias and the exclusion of pathologically normal hearts.[34] Among unselected cases of sudden cardiac arrest with a negative autopsy in young people, a molecular autopsy reveals a relevant cardiac gene variant in 27% of cases.[35]

Figure 2 shows the breakdown of causes of death in athletes according to data aggregated from studies that included autopsy-negative, sudden, unexplained death as a potential cause.[22,24,27,28,33,36-38] Concern about the cardiac effects of coronavirus disease 2019 (Covid-19) led to widespread screening of athletes after infection with severe acute respiratory syndrome coronavirus 2, with the reported incidence of clinical myocarditis ranging from 0.3 to 0.6%.[39] A recent study that examined sudden death from cardiac causes in NCAA athletes over a 20-year period that ended in June 2022 showed no increase in sudden death from cardiac causes after 2020.[27] Specific causes of sudden death in athletes are discussed in detail in the Supplementary Appendix. Noncardiac causes of exercise-related death, such as heat stroke or sickle cell disease, are not considered here.

PREVENTION OF SUDDEN DEATH FROM CARDIAC CAUSES IN ATHLETES

In the general population, prevention of sudden cardiac arrest and death in athletes includes both primary prevention by means of screening before participation and secondary prevention with the use of emergency action planning. For some sports, chest protectors are required to prevent commotio cordis and should meet appropriate standards.[40] For the athlete returning to play after surviving sudden cardiac arrest, disease- and sport-specific measures to reduce the likelihood of recurrence are critical. Similarly, for those with diagnosed cardiovascular disease who are returning to play, disease-specific risk assessment for sudden cardiac arrest and implementation of recommended preventive measures are required.

SCREENING FOR CONDITIONS THAT PREDISPOSE TO SUDDEN CARDIAC ARREST AND DEATH

One in 300 people 35 years of age or younger has a condition associated with sudden cardiac arrest and death.[41] How to best screen for these conditions remains an area of controversy. History taking and physical examination are recommended by the American Heart Association as the primary approach to screening, but used alone, they have both low sensitivity and a high incidence of false positive results.[41] A 12-lead electrocardiogram (ECG) identifies disorders associated with sudden death from cardiac causes in about two thirds of cases, including cases of hypertrophic cardiomyopathy, other cardiomyopathies, and electrical disorders such as the Wolff–Parkinson–White syndrome and long QT syndrome; this approach outperforms history taking and physical examination alone, with a low incidence of false positive results when contemporary standards for ECG interpretation in athletes are followed.[42]

In a meta-analysis of ECG and other screening tools that included 47,137 athletes, the most common diagnosis was the Wolff–Parkinson–White syndrome, detected in 1 in every 703 athletes; the prevalence of hypertrophic cardiomyopathy and that of long QT syndrome was 1 in 2613.[41] In an Italian population-based study, cardiovascular screening decreased the incidence of sudden death from cardiac causes among athletes by 89% over a 20-year period, although methodologic concerns limited the definitiveness of the data.[43] This finding was not replicated in an Israeli study, which also had methodologic limitations.[44] Studies investigating the effect of screening with history taking and physical examination alone (without ECG) on the risk of sudden death from cardiac causes are lacking. Although ECG adds to the cost of screening, the added sensitivity results in a significantly lower cost per diagnosis.[45]

The NCAA recognizes that many schools incorporate ECG in screening and has recommended standards for those that do.[46] With the use of an appropriate technique, echocardiography can identify most coronary-artery anomalies,[47] as well as proximal aortopathy and congenital conditions not associated with sudden cardiac arrest and death, such as a bicuspid aortic valve. However, data on the additional benefit of echocardiographic screening are limited, and its use adds complexity and cost. The appropriate screening strategy depends on the resources available, risk tolerance, and the population being screened. In addition, a one-time screening does not rule out cardiac disease over time, because some disorders may be acquired (e.g., myocarditis), exhibit phenotypic variability (e.g., long QT syndrome), or evolve (e.g., cardiomyopathy).[19,23] Athletes with ECGs that border on abnormal and a workup that is negative for cardiac conditions should undergo follow-up screening. Cardiovascular screening can be reasonably repeated every 2 to 3 years until the athlete is 25 years of age. Cardiovascular screening in athletes older than 25 years should include an assessment of risk factors for atherosclerotic disease, with additional assessment as clinically indicated.[48]

EMERGENCY ACTION PLANS

Prompt recognition of sudden cardiac arrest and early treatment with defibrillation are critical for survival.[16] Emergency action plans, along with routine rehearsal of the plans, are required (or recommended) by most professional sporting organizations and those that govern high-school and college sports.[46,49] Any athlete who has collapsed and is nonresponsive should be considered to be in cardiac arrest, and an automated external defibrillator (AED) should be applied. If an athlete is not in cardiac arrest, no shock will be delivered. Agonal breaths and tonic–clonic movements during sudden cardiac arrest can lead bystanders to delay time-critical treatment. An interval of less than 3 minutes between collapse and shock improves the outcome, and emergency action plans should be developed to meet this target. A well-planned emergency action plan includes activation of emergency medical services (EMS), early cardiopulmonary resuscitation, and early defibrillation. Emergency action plans should include plans for routine maintenance of AEDs and associated supplies, as well as coordination with local EMS providers. Survival among athletes with sudden cardiac arrest has increased over the past two decades, and the most recently reported survival ranges from 48 to 89% (Fig. 3).[21,22,24,31,50-54]

DIAGNOSTIC EVALUATION AFTER RETURN OF SPONTANEOUS CIRCULATION

Diagnostic evaluation of an athlete who has survived sudden cardiac arrest should be similar to that for any survivor of cardiac arrest of a similar age. Causes mirror those in sudden death from cardiac causes, as enumerated above, but ECG and functional studies in survivors may lead to the diagnosis of a specific disorder that would not have been identified at autopsy (i.e., one that would have led to classification as autopsy negative) in an athlete who did not survive sudden cardiac arrest. Evaluation starts with history taking, physical examination, and ECG and includes elements that are common to the evaluation of all survivors of sudden cardiac arrest, with an additional focus on athlete-specific features. Exercise-related events are often associated with arrhythmogenic right ventricular cardiomyopathy,[55] catecholaminergic polymorphic ventricular tachycardia,[56] and anomalous coronary arteries.[27]

The evaluation should include an inquiry about performance-enhancing drugs.[16] A review of video, which is often recorded at both competitions and practice, may also provide clues.[16] A history or video of a hit in the chest is suggestive of commotio cordis.[40] However, underlying structural or electrical heart disease must be ruled out before commotio cordis is diagnosed.[16] ECG may indicate a diagnosis of long QT syndrome; however, ECGs in patients who have been resuscitated commonly show a prolonged corrected QT interval, which frequently returns to normal after 3 to 5 days.[57] The ECG will also detect the Wolff–Parkinson–White syndrome or ST-segment elevation myocardial infarction and may indicate the presence of Brugada syndrome. Toxicology analysis may elucidate contributors to sudden cardiac arrest, although the results are less often positive in athletes than in nonathletes.

The next step in the evaluation is echocardiography, which can indicate hypertrophic cardiomyopathy, arrhythmogenic cardiomyopathies, and other cardiomyopathies, as well as bileaflet arrhythmogenic mitral valve prolapse. Although ECG can be abnormal in patients with cardiomyopathies, the sensitivity for hypertrophic cardiomyopathy is 75 to 90%[58] and may be lower for other cardiomyopathies.[59] Echocardiography is also less sensitive for cardiomyopathies, such as apical hypertrophic cardiomyopathy or arrhythmogenic right ventricular cardiomyopathy, than is cardiac magnetic resonance imaging (MRI), which should be the next step if the diagnosis remains uncertain after ECG and echocardiography.[59,60]

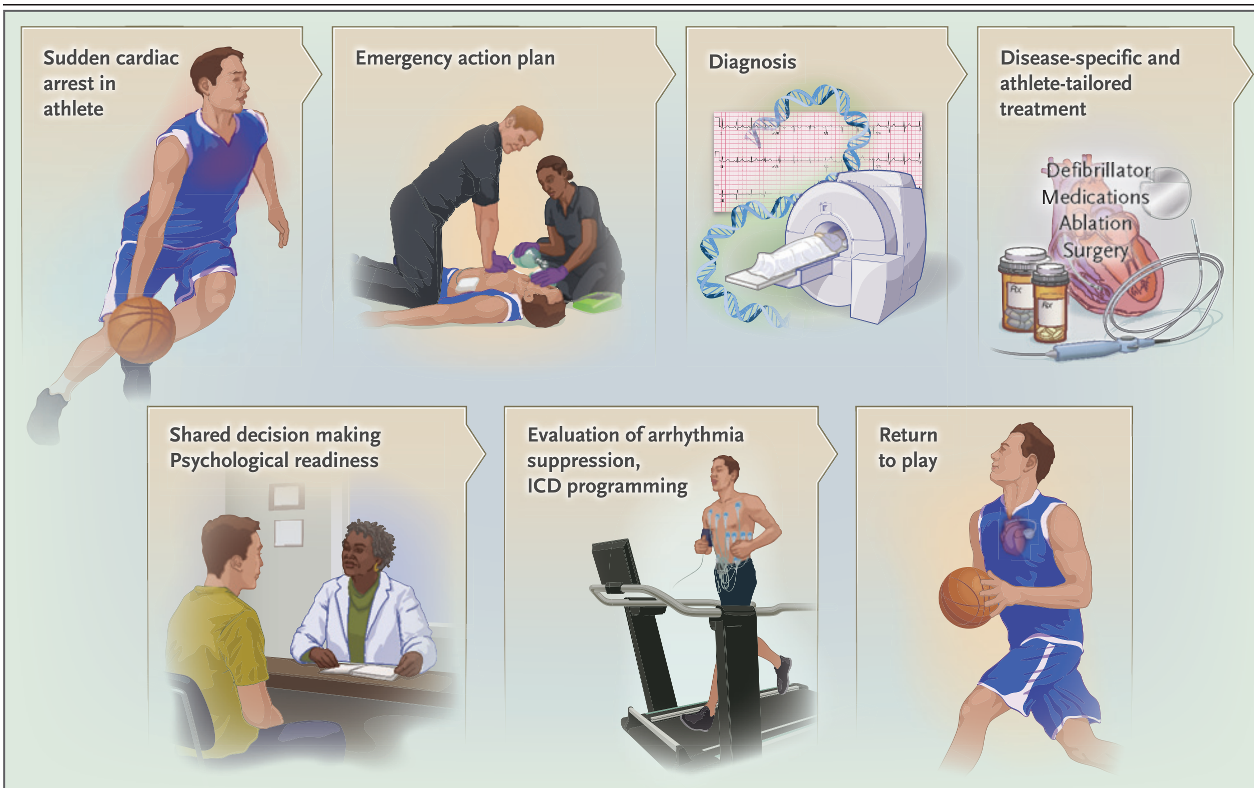

Figure 4. Return to Play for Athletes Who Survive Sudden Cardiac Arrest.
Current statements from professional societies support shared decision making regarding return to play for many athletes who survive sudden cardiac arrest, with factors such as underlying heart disease, the athlete's sport, and the athlete's goals and preferences taken into account.[16,48] ICD denotes implantable cardioverter–defibrillator.

For athletes in whom structural heart disease is diagnosed, the presence of fibrosis on cardiac MRI is an important addition to the risk assessment. However, fibrosis is seen in 38% of healthy athletes, particularly at the right ventricular insertion site.[61] The left ventricular ejection fraction may be transiently depressed after cardiac arrest.

Because normal cardiac adaptation to vigorous exercise can mimic the abnormal findings of cardiomyopathies, imaging tests in athletes should be interpreted by experts with an understanding of cardiac athletic adaptation,[17] as well as an understanding of the sequelae of sudden cardiac arrest. Coronary computed tomography (CT) angiography remains the standard for the detection of an anomalous coronary artery.[47]

If the diagnosis remains elusive, evaluation for diseases that affect the electrical system, such as channelopathies, is the next step. Exercise testing, particularly with the use of a burst protocol, can induce ventricular arrhythmias in patients with catecholaminergic polymorphic ventricular tachycardia, which is characterized by normal results on resting ECG. Challenge with intravenous administration of a sodium blocker such as procainamide can reveal Brugada syndrome. Genetic testing may be useful if the diagnosis remains unclear, and it is also useful for evaluation of family members if a potentially inherited entity has been diagnosed in the athlete.

A detailed diagnostic algorithm for evaluating athletes with sudden cardiac arrest has been published previously.[16] Additional details about causes of sudden cardiac arrest in athletes are provided in the Supplementary Appendix.

APPROACH TO DECISION MAKING ABOUT A RETURN TO PLAY

Most conditions leading to sudden cardiac arrest, as well as treatments such as the implantable cardioverter–defibrillator (ICD), were historically considered to be contraindications for a return to vigorous, competitive exercise because of concern about the risk of sudden death from cardiac causes.[62] However, increasing data have suggested that many athletes who have survived sudden cardiac arrest and are appropriately treated can return to sports without having a high risk of recurrence. These data, in combination with the evolution toward a more patient-centered approach to medical decision making, have led to major changes in recommendations by professional societies with regard to a return to play for athletes who have survived sudden cardiac arrest; such recommendations now emphasize a shared decision-making approach.[48] For most cardiac diseases leading to sudden cardiac arrest, the approach has moved from whether they can return to play to how they can return to play (Fig. 4).

The first step is disease-specific treatment. For most survivors of sudden cardiac arrest, this includes ICD implantation. If commotio cordis is definitively diagnosed after underlying heart disease has been ruled out, further treatment is not required. Athletes in whom a fully reversible cause is identified can return to play after treatment, such as ablation of the accessory pathway in athletes with the Wolff–Parkinson–White syndrome. For a minority of heart diseases, other treatments may be adequate to prevent recurrence, such as medical or denervation therapy in some channelopathies or surgical treatment in anomalous coronary or congenital heart disease. Risk assessment and treatment should be individualized, with expert guidance. However, for most entities that lead to sudden cardiac arrest, including cardiomyopathies and most electrical diseases, as well as sudden cardiac arrest for which no diagnosis has been identified (idiopathic ventricular fibrillation or unexplained cardiac arrest), ICD implantation is indicated for secondary prevention.[16,63]

After the athlete has undergone disease-specific treatment, shared decision making about the return to play starts with a discussion of the athlete's values and preferences.[64] Shared decision making requires discussion of the available data on a return to play that addresses the athlete's specific condition and sport, as well as the limitations of the data. Risk tolerance is discussed in the context of the athlete's goals. Although delineation of the roles of clinicians, patients, and teams continues to evolve with some debate,[65] the initial discussion between the patient and physicians should be followed by a collaborative discussion among all stakeholders, including treating physicians, team physicians, and institutional stakeholders (schools, leagues, athletic departments, and trainers) in order to integrate medical knowledge, clinical uncertainty, the athlete's and family's values, and institutional philosophy and risk tolerance.[66]

DATA AND RECOMMENDATIONS FROM PROFESSIONAL SOCIETIES

The largest registry of data from athletes who returned to play after sudden cardiac arrest, the multinational prospective ICD Sports Registry, included 201 athletes with a history of sudden cardiac arrest as the indication for ICD implantation (of a total of 440 athletes with ICDs who were included in the registry).[67] After a mean follow-up of 44 months, there were no deaths, cardiac arrests, or failures to convert an arrhythmia during sports, nor were there any sports injuries related to arrhythmias or shocks. Both appropriate and inappropriate shocks were delivered, during competition, practice, or other physical activity or at rest, but most of the athletes returned to sports after receiving a shock. The incidence of system malfunction was similar to that among unselected patients with ICDs in previous case series.[67]

In a recent study involving elite athletes (professional or NCAA Division I intercollegiate athletes) who had returned to competition after a diagnosis of genetic heart disease, eight had a history of sudden cardiac arrest.[68] Among these eight athletes, one received an appropriate shock that was not associated with exercise; there were no deaths or cardiac arrests. On the basis of these data, the 2025 American Heart Association–American College of Cardiology scientific statement on Clinical Considerations for Competitive Sports Participation for Athletes with Cardiovascular Abnormalities[48] and the 2024 Heart Rhythm Society Expert Consensus Statement on Arrhythmias in the Athlete[16] indicate that a return to play is reasonable for an athlete who has had a sudden cardiac arrest with subsequent ICD implantation. However, the European Society of Cardiology suggests restricting athletic participation after sudden cardiac arrest for athletes with certain diseases.[69] All the statements emphasize the importance of expert assessment by sports cardiologists, as well as disease-specific specialists such as electrophysiologists or cardiomyopathy experts.

There are important caveats, however, that guide personalized discussion of the underlying disease and sport. Although many of the athletes with ICDs who have been included in published case series played soccer or basketball, high-level athletes with ICDs who returned to collision sports such as tackle football have not been described, and the risk of system damage may be higher for such athletes. Also, the underlying diagnosis plays a role — extensive, vigorous exercise may increase the risk of disease progression in desmosomal genetic cardiomyopathies[70] and possibly in lamin A and C and filamin C arrhythmogenic cardiomyopathies.[16] The effect of vigorous exertion on the progression of other arrhythmogenic cardiomyopathies is under investigation. For hypertrophic cardiomyopathy, current U.S. guidelines state that a return to play is reasonable,[16] is reasonable to consider,[48] or may be considered,[58] with an individualized risk assessment taken into account.

Assessment of psychological readiness for a return to play is an important step. Both survivors of sudden cardiac arrest in the general population[71] and athletes returning to play after less life-altering events[72] have psychological distress. Care providers should be cognizant of both illness-related and sports-related psychological needs.

CARE OF AN ATHLETE WHO RETURNS TO PLAY AFTER A SUDDEN CARDIAC ARREST

The choice of both device and nondevice therapies after sudden cardiac arrest should be guided by considerations that are specific for the athlete. ICDs approved by the Food and Drug Administration include transvenous and subcutaneous devices, as well as the recently approved extravascular ICD. The pros and cons of each device for the general population include a higher incidence of lead complications with the transvenous device and a larger generator and fewer capabilities with the subcutaneous device.[73] For the athlete, specific considerations include the extent of upper-extremity repetitive motion, or extensive weight lifting, which may increase the risk of lead fracture in a transvenous device,[16] a factor that favors a subcutaneous device for swimmers or rowers. For collision sports, the more prominently located generator and extrathoracic lead

KEY POINTS

SUDDEN CARDIAC ARREST IN ATHLETES

- The incidence of sudden cardiac arrest in athletes varies according to age, race and ethnic group, sex, social determinants, and sport.
- Causes of sudden cardiac arrest include cardiomyopathies, electrical disease, coronary-artery anomalies, and other structural abnormalities. The incidence of sudden cardiac arrest in college athletes has not increased during the time frame of the coronavirus disease 2019 (Covid-19) pandemic.
- Prevention strategies include both screening for cardiovascular disease before participation in the sport and emergency action planning.
- Diagnostic evaluation of athletes who survive sudden cardiac arrest should follow that for nonathletes in the same age group, but with attention to sport-specific causes, and should be performed by medical professionals with expertise in the interpretation of test results in the context of athletic adaptation.
- Accumulating data indicate that many athletes who survive sudden cardiac arrest can return to sports without excess risk after undergoing appropriate disease-specific treatment. For many — although not all — cardiac diseases, professional societies now view a return to play after sudden cardiac arrest as reasonable or something that may be considered, through shared decision making, with emergency action plans and follow-up in place.
- As some athletes who survive sudden cardiac arrest are returning to play, decisions about management of cardiac conditions should take sports participation into account.

of the subcutaneous device may hypothetically increase the risk of damage, and this possibility is currently under investigation. In the ICD Sports Registry, programming with a high heart-rate cutoff and long duration was associated with fewer appropriate and inappropriate shocks without an increase in syncope.[74]

The potential for arrhythmia recurrence should be assessed before a return to play. Monitoring or interrogation of ICDs to detect arrhythmia at rest, with stress testing to detect exercise-induced arrhythmias, was included in the protocol for a series of athletes who returned to play successfully.[68] Stress testing should reproduce the type of sport when possible and be terminated for symptoms, arrhythmia, or exhaustion at maximal effort rather than for achievement of an age-predicted target heart rate or completion of the protocol.[17] For an athlete with an ICD, stress testing also confirms the heart rate, as well as appropriate sensing, which is particularly relevant in the case of athletes with the subcutaneous device, since T-wave oversensing can occur with this device. For athletes with arrhythmic conditions that are treated medically, either as primary treatment or for reduction of ICD shocks, stress testing aids in the evaluation of the adequacy of arrhythmia suppression.

Finally, long-term follow-up is critical. Remote monitoring improves outcomes for athletes with ICDs and is recommended for all such athletes. After a shock has been delivered, the underlying cause should be determined and addressed before a return to play. Recurrent arrhythmias should be treated as appropriate, with medications, ablation, or sympathetic denervation, and the efficacy of suppression should be documented with monitoring and stress testing before a return to play. If an inappropriate shock is delivered because of a system malfunction or a sensing issue, the system should be revised as indicated.

CONCLUSIONS AND FUTURE DIRECTIONS

Sudden death from cardiac causes in an athlete is a tragedy that may be preventable by means of screening before participation and emergency action planning. These approaches are complementary — screening will never be 100% sensitive, and emergency action plans will never cover all athletes in all locations. Further research is needed to determine the best screening methods and practices. Research on implementation will continue to enhance processes and protocols for emergency action plans. Advocacy at the state and federal levels to increase AED availability and to provide safer training environments is critical for improving the safety of athletes.

For the athlete who survives sudden cardiac arrest, ongoing research will enhance diagnostic capabilities and tailoring of treatments to prevent recurrence. Ongoing studies such as the

Outcomes Registry for Cardiac Conditions in Athletes[75] will continue to expand our understanding of outcomes in athletes with cardiovascular disease who return to play, at all levels of a sport. The overall goal is to prevent sudden cardiac arrest in athletes and, for survivors of cardiac arrest who wish to continue their participation in sports, to facilitate a return to play while minimizing risk.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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