Scholars LITERATURE

International Journal of Integrative Cardiology

Review Article

DOI: https://doi.org/10.47275/2690-862X-136
Volume 5 Issue 1

# A Comprehensive Review on Sudden Cardiac Death in Young

**Shaik Ameer Sohail[1*], Joshithasree Pudur[2], Sujan Gowda[3] and Komatireddy Swetcha Reddy[4]**

[1]Southwestern University, PHINMA, CEBU, Philippines

[2]Sri Venkateswara Medical College, Tirupati, Andhra Pradesh, India

[3]Dr. B.R. Ambedkar Medical College, Bengaluru, Karnataka, India

[4]Mallareddy Medical College for Women, Hyderabad, Telangana, India

## Abstract

While the occurrence of sudden cardiac death (SCD) in a young individual is a rare occurrence, it is a distressing event that often receives widespread attention. In recent times, SCD among this demographic has increasingly been recognized as a concern for public health and safety. This analysis presents current information pertaining to the epidemiology of SCD and strategies for prevention, resuscitation, and identification of those at high risk. Areas of ongoing research and debate include the establishment of optimal screening practices, approaches for assessing risk levels, postmortem evaluation, and identification of adjustable obstacles to improving outcomes following resuscitation of young SCD patients. The establishment of a national registry for SCD in young individuals will provide valuable data to address these inquiries.

**Keywords:** Sudden cardiac death, Optimal screening practices, Epidemiology

[*]***Correspondence to:*** Shaik Ameer Sohail, Southwestern University, PHINMA, CEBU, Philippines, E-mail: sohailshaik032@gmail.com

***Citation:*** Sohail SA, Pudur J, Gowda S, Reddy KS (2023) A Comprehensive Review on Sudden Cardiac Death in Young. Int J Integr Cardiol, Volume 5:1 (136). DOI: https://doi.org/10.47275/136

**Received:** December 15, 2023**; Accepted:** December 26, 2023**; Published:** December 29, 2023

## Introduction

The sudden, unanticipated death of a young person is one of the most traumatic medical events. Though SCD is statistically rare in young people, its dramatic presentation and cascading effects on families and communities make it newsworthy [1]. SCD cases in athletes represent a hidden vulnerability lurking in a strong, healthy young person. Lay public concern about SCD in children and teenagers is high, compared with more prevalent deadly childhood risks, such as accidents, injuries, suicide, and violence. However, it is equitable to regard SCD in young individuals as a matter of public health and to formulate approaches based on evidence and expert consensus to alleviate it. This analysis will explore the present state of knowledge and practice concerning SCD in the youth. This will encompass the pathophysiology of SCD, the disease mechanisms that make individuals susceptible to it – particularly among asymptomatic young people – and methods for resuscitation and identification of those at potential risk [2]. Since numerous primary causes of SCD in the young are genetically determined, the sudden demise of a young individual often necessitates examination within the familial context. Advancements in cardiovascular genetics have contributed both molecular understanding and increased intricacy and uncertainty to our comprehension of affected families. Both pre-death and post-death genetic testing now offer the prospect of disease-specific risk assessment and treatment for surviving relatives of SCD patients. Furthermore, SCD in young people affects the community. These events require public health policy responses to provide rational and effective strategies to protect our youth from rare but dramatic occurrences. Among these strategies may be cardiovascular screening programs, the deployment of defibrillators in public access areas, the establishment of standards for postmortem investigations of SCD, and the establishment of regional and national registries [3].

As this review covers such a broad range of topics, it is limited in its depth, in general, and with respect to the various cardiac etiologies that predispose to SCD (including congenital heart disease). Resuscitation outcomes, science, and epidemiology will be exceptions [4].

## Epidemiology and Etiologies of SCD in the Young

### Epidemiology

Childhood SCD is not frequently seen, and to obtain accurate statistics on its incidence and risk factors, it is essential to conduct well-designed studies at regional or multicenter levels. Table 1 displays the occurrence of SCD in various younger populations and settings. This emphasizes the inherent variability in these estimations and clearly demonstrates that the rate of SCD in children is significantly lower (1 to 2 orders of magnitude) compared to adults. The incidence ranges from less than 1 to 10 deaths per 100,000 individuals per year (excluding infants and those above 18 years old, less than 1 to 4 deaths per 100,000 individuals per year). The impact of SCD on the loss of life-years is disproportionately greater for children due to their longer life expectancy [6, 7]. These statistics are crucial for the development of effective public health policies focused on early detection, prevention, and treatment. Important contributing factors include age, gender, presence of other medical conditions, geographic location, and participation in sports (Figure 1).

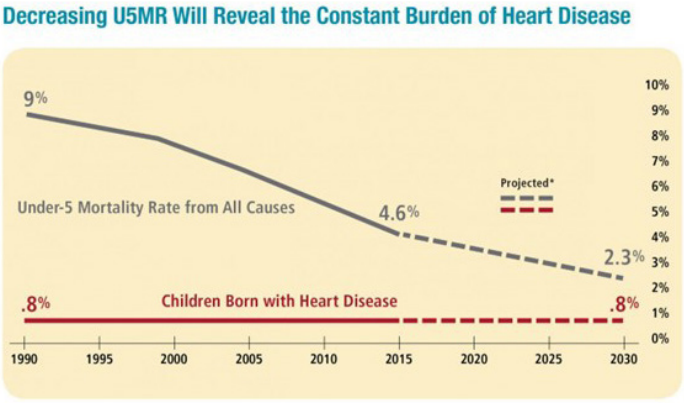


**Figure 1:** Mortality rates among children due to heart disease [5].

SCD incidence is best determined by population-based studies that have a large, well-defined denominator. The rarity of SCD in young individuals necessitates surveying national or regional populations over long periods of time. Most of these studies have relied on retrospectively analyzing administrative databases, utilizing EMS databases, or using ad hoc methods such as Internet searches or reviewing news media [8-10]. However, this approach introduces uncertainty in both overdiagnosis and underdiagnosis. A prospective analysis of SCD in patients of all ages indicated that relying on death certificates tends to overestimate SCD events. Case series of SCD allow for accurate identification of affected cases and are valuable in determining etiology and mechanisms [11]. While they provide an estimate of the overall problem, they cannot reliably quantify the population at risk.

Determining the prevalence of SCD is most effectively achieved through population-based research that has a substantial and clearly defined denominator. Given the rarity of SCD in young individuals, these studies must conduct comprehensive surveys of national or regional populations over extended periods. The majority of these studies have relied on retrospective analysis of administrative databases, utilization of EMS databases, or utilization of improvised methods such as online searches or examination of news media. These techniques introduce uncertainty in identifying both over- and underdiagnosis. A prospective investigation of SCD in patients of all ages indicated that relying on death certificates tends to exaggerate the number of SCD occurrences [13, 14]. Case series of SCD provides a reliable approach to identifying affected cases and is valuable in determining the causes and mechanisms of SCD. They also offer an estimation of the overall magnitude of the problem, although they cannot accurately ascertain the size of the population at risk (Figure 2).

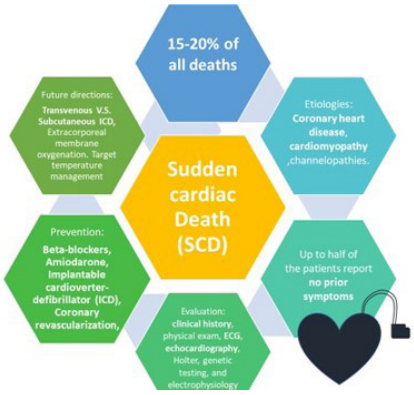


**Figure 2:** Incidence and etiology (coronary artery disease, cardiomyopathy, channelopathies, etc.) [12].

Over the past few years, voluntary registries have emerged to monitor the occurrence of SCD in young people living in stable communities for a prolonged period. This method tackles certain deficiencies found in previous techniques by adopting a prospective and problem-specific approach, which ensures the relative accuracy and completeness of data available for analysis [15]. The National Institutes of Health, in collaboration with the Centers for Disease Control and Prevention, is currently in the process of developing a nationwide registry for sudden unexpected deaths in the young population across various regions. This endeavor is expected to expand in the future. Our present understanding of the subject largely stems from the collection of local data or research registries encompassing individuals of all ages and causes [16].

Relevant demographic factors that are important in the occurrence of SCD among young populations can be obtained from existing data. The occurrence of sudden unexpected death, as well as SCD specifically, is influenced by age [17]. While the risk of unexpected death is higher during early infancy due to noncardiac causes and sudden infant death syndrome, the prevalence of SCD decreases during early childhood and then starts to rise again during adolescence. This pattern is illustrated by a large national study that identified 114 cases of SCD in children aged 1 to 18, with a total observation period of nearly 8 million patient-years. Similar patterns have been observed in comprehensive surveys conducted in Ontario and 10 other sites in North America, which together form the Resuscitation Outcomes Consortium [18].

### SCD associated with cardiovascular disorders

The case series approach had proven effective in categorizing cardiovascular diseases that lead to SCD in young individuals. By understanding the relative prevalence of these underlying diseases, we can estimate the relative risks of experiencing cardiac arrest. There are several general categories of causes, including hereditary and acquired cardiomyopathies, arrhythmia syndromes (channelopathies), congenital heart defects, myocarditis, and coronary abnormalities [19, 20]. In some cases, the patient may already be aware of these underlying diagnoses, while in others they may be undiagnosed and not yet showing symptoms. The proportion of detected versus undetected risk of SCD varies depending on the specific diagnosis, as does our ability to reduce the risk of cardiac arrest through preventative measures and prophylactic therapy. These factors significantly impact the usefulness of diagnostic screening for asymptomatic individuals, a topic that will be explored further in this article [21].

## Cardiomyopathies - Heritable and Acquired

The hereditary heart conditions known as hypertrophic cardiomyopathy (HCM), arrhythmogenic right ventricular cardiomyopathy (ARVC), dilated cardiomyopathy, and left ventricular noncompaction cardiomyopathy, as well as the hereditary channel conditions like long QT syndrome (LQTS), short QT syndrome, Brugada syndrome, and catecholaminergic polymorphic ventricular tachycardia, are potentially fatal but highly manageable genetic heart diseases. The estimated occurrence of each of these conditions varies, but it is believed that HCM affects approximately 1 in every 500 individuals and LQTS affects approximately 1 in every 2000 individuals [22].

## Congenital Heart Disease - A Global Concern

Congenital heart disease (CHD) affects about 40 000 children in the United States every year. In severe and mild forms of CHD, ventricular dysfunction leads to scarring, hypertrophy, and fibrosis, which increases the risk of heart attack [23]. The rate of SCD is 15% to

25% when CHD patients reach early adulthood, and CHD patients are more likely to suffer from it.

Constructing an aggregated risk estimate for SCD in CHD patients is challenging due to the diverse nature of the condition. However, when compared to patients with acquired heart diseases like dilated or ischemic cardiomyopathy, the incidence of SCD in CHD patients is generally lower. The tetralogy of Fallot, a well-studied form of CHD with a relatively high prevalence and extensive follow-up after surgical palliation, has an average SCD rate of 0.1% to 0.2% per year. However, there are other lesions and subgroups of patients that are likely to have a significantly higher risk for SCD [24]. It is probable that ventricular tachycardia, atrial arrhythmia, and heart block with paroxysmal bradycardia all contribute to some extent, and the prevalence of each type of arrhythmia increases with age.

## SCD in Athletes

Young individuals who are involved in sports and have a significant public presence are a crucial subgroup. They have been extensively researched in relation to the occurrence of SCD. In the United States, there is widespread participation in sports among the youth, with over 40 million participants and approximately 7.5 to 8 million teenagers participating in organized high school sports [25]. The media often highlights cases of SCD in young athletes, leading to the assumption that sports involvement directly causes SCD. Estimates of SCD occurrence in athletes vary greatly, ranging from 1 in 3000 per year among male basketball athletes in NCAA Division 1 to 1 in 917,000 per year among high school athletes in Minnesota. Research on college athletes indicates an annual incidence between 1 in 43,000 and 1 in 67,000. This risk is 2 to 3 times higher than the general population, but it may be influenced by demographic factors such as sex, age, and ethnicity that are correlated with sports participation [26-28].

## Etiology of SCD in Younger Athletes

A preliminary study exploring the causes of SCD in young athletes was conducted in Italy. The study focused on a group of 22 young athletes who experienced SCD and identified ARVC as the main cause. A more comprehensive autopsy study conducted in the same region on young adult athletes revealed that ARVC and coronary artery disease were responsible for over 50% of the approximately 200 cases analyzed

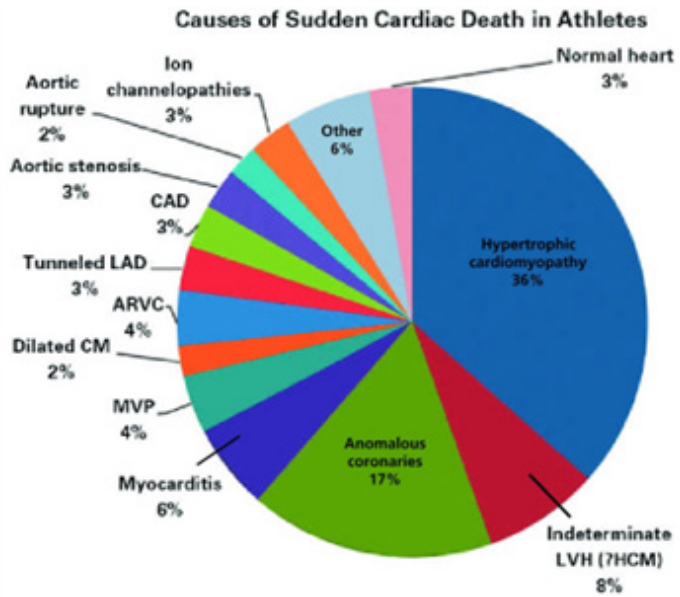


**Figure 3:** Cause of SCD in athletes.

that had identifiable heart conditions (Figure 3). The remaining cases were attributed to valvular heart disease, nonatherosclerotic coronary artery abnormalities, myocarditis, and abnormalities in the conduction system [29].

Research conducted in the United States on SCD in athletes indicated that HCM is likely the primary cause of this phenomenon. A comprehensive registry that documented 1866 instances of SCD in athletes over a span of more than 25 years found that 1049 cases were linked to cardiovascular issues [30]. Among these cases, a majority were able to be diagnosed with a specific condition. The study identified HCM and congenital abnormalities in the coronary arteries as the most common diagnoses. However, other studies have found that sudden death cases with negative autopsy results were the most frequent occurrence [31].

Identifying individuals who are at risk, implementing protective measures, and allocating resources to respond to cardiac arrests during sports events have become important due to the significant role of sports in society. The American and European professional societies have released comprehensive guidelines, including the Bethesda Guidelines and the European Society of Cardiology Consensus Recommendations. Although these documents have been developed based on extensive reviews of past and present information, they vary in certain aspects and have led to the establishment of various mandatory and voluntary policies for screening athletes for cardiovascular health and determining eligibility for competitive sports. Updated guidelines addressing these matters were published in late 2015 [32]. These guidelines largely reiterate the recommendations made a decade ago, although there has been a significant change concerning cardiac channelopathies. Unlike the previous approach that often led to automatic disqualification in most sports, there is now a recognition that shared decision making, respect for patient/family autonomy, and informed choice to compete are important. Moreover, this approach is in accordance with the 2013 guidelines for managing LQTS, which emphasize that athletes with LQTS should consult a specialist if they wish to compete [33, 34].

According to reports, some individuals at an increased risk of developing SCD may not be able to follow these guidelines and therefore be prohibited from participating in certain sports. These guidelines explicitly prescribe recreational and competitive sports for patients with increased SCD, but anecdotal evidence suggests that many patients with increased SCD do so. Medical diagnoses have disqualified athletes in high-profile legal cases [35].

## Chest Trauma Associated SCD

Commotio cordis, also known as blunt chest trauma in the normal juvenile heart, is an infrequent occurrence in SCD. Determining the frequency of this event is difficult, but research on SCD in intercollegiate NCAA events shows that autopsy negative SCD is a relatively common discovery, and some cases can be clearly linked to trauma based on historical information [36]. Animal studies have revealed a possible mechanism for commotio cordis, which involves chest trauma occurring at the same time as a vulnerable repolarization interval, affecting the ventricle. Certain sports, including baseball, cricket, lacrosse, soccer, hockey, football, and martial arts, have a higher probability of experiencing these occurrences. This holds true whether in competitive or recreational settings [37].

## SCD due to the Use of Medications

Recent population-based studies have largely resolved concerns regarding how stimulant medications affect the risk of SCD in young people, in contrast to the debate surrounding the management of

SCD risk in athletes [38]. Approximately 2.5 million children in the United States were treated with stimulant medications in 2003 for attention deficit, hyperactivity disorder, and other school and social functioning disorders. Many of these medicines have small but measurable sympathomimetic effects. Some of these drugs possess sympathomimetic properties of small yet detectable magnitudes. A perceived group of SCD incidents in patients being administered stimulants for attention deficit and hyperactivity disorder resulted in the discontinuation of a specific medication (a methylphenidate formulation) in Canada, issuance of a public health advisory, and a cautionary statement in the form of a black box warning by the United States Food and Drug Administration concerning the use of stimulant medications, along with a recommendation for pre-treatment electrocardiographic assessment prior to commencing therapy [39,40]. However, subsequent epidemiological investigations utilizing extensive administrative databases clearly indicate that such drugs have no impact, and conceivably even exert an adverse, health-user effect on the prevalence of SCD.

Recent data from a large LQTS registry about the use of stimulant medications in LQTS patients counterbalances these findings, suggesting that these medications are associated with an increased risk of cardiac events, particularly in males. However, a concurrent, smaller retrospective study found no such effect, indicating that consensus has not yet been reached about whether stimulant medication is safe in LQTS.

## Identifying the Young Patients at Risk of SCD

### Signs and screening

SCD is associated with certain prodromal symptoms and clinical events. The specific predictive power of these markers allows them to be incorporated into calculations regarding diagnostic screening or, if known diseases exist, primary prevention using medical therapy.

Aborted or resuscitated sudden cardiac arrest serves as the most trustworthy presenting symptom that specifically points to the probable existence of a primary cardiac diagnosis. The occurrence of repeated episodes of cardiac arrest in these individuals is widely acknowledged, to the extent that it forms a considerable portion of ICD implantations carried out on young patients, [2] even if a definite diagnosis cannot be determined and the patient is labeled as having idiopathic ventricular fibrillation by default.

Commonly linked prodromal symptoms related to the risk of SCD include palpitations, chest discomfort, loss of consciousness, and convulsions. These symptoms indicate temporary changes in heart rate and blood pressure caused by short episodes of irregular heart rhythm. Studies on unexpected SCD in seemingly healthy children suggest that a significant proportion, possibly between one-fourth and one-half, may have experienced a preceding symptom, often syncope or convulsions. However, palpitations, chest discomfort, and syncope are common in healthy children, therefore their diagnostic value as standalone indicators is limited. An exception to this is exertional syncope, which is strongly associated with cardiac disease [41]. When combined with other signs of cardiac disease, any of these symptoms may suggest an increased risk.

### The importance of screening for SCD in young people

Numerous suggestions have been made for SCD screening programs, either on a societal level or specifically for high-risk subpopulations such as athletes. A working group at the National Heart, Lung, and Blood Institute has recently studied this matter [42]. To address this issue, one can employ general principles used to assess the clinical usefulness of a screening test. Firstly, the test must possess diagnostic sensitivity for the target disease. The disease should not be excessively uncommon and should carry the potential for life-threatening consequences as an initial occurrence. The cost of the test and the potential expenses associated with a false-positive diagnosis should be minimal. Lastly, effective treatments should be accessible.

Different methods for screening cardiovascular conditions have been proposed, such as ECG, medical history and physical examination, and echocardiogram, either separately or in combination. The accuracy and reliability of these tests for detecting heart problems depend on the specific condition being screened for and its prevalence among the population being tested. Studies analyzing different screening approaches have been conducted in various communities and age-defined groups (e.g., newborns for identifying LQTS) as well as individuals involved in sports or taking stimulant medications [43]. Existing literature suggests that ECG is a highly sensitive and effective screening tool for most conditions that can lead to sudden cardiac death in young individuals, including LQTS, Wolff-Parkinson-White syndrome, HCM, and Brugada syndrome. Different coding systems have also been developed to enhance the usefulness of ECG in screening for these conditions.

Cost-ineffective or marginally cost-effective findings have been reported in cost-effectiveness studies on screening in asymptomatic youth. These studies, which are sensitive to assumptions, present a range of possible results in sensitivity analysis [44]. Nevertheless, they indicate that ECG screening in most scenarios is not cost-effective, or only slightly so, primarily due to assumptions about baseline disease prevalence and the efficacy of available treatments. To enhance cost-effectiveness, it may be beneficial to focus on high-risk groups, such as NCAA Division 1 athletes, provided effective measures can be implemented to mitigate their risks. Additionally, screening for LQTS in infancy may offer significant additional protection by enabling early identification of arrhythmic disease in certain groups [45].

Several self-organized advocacy groups have shown a high level of proficiency in structuring cardiac screening programs, based on the application of existing guidelines. Although mandatory cardiovascular screening is widely accepted in some countries as a public policy, practical concerns have limited enthusiasm for it in the United States and abroad [46]. Chief among these is:

1. False-positive findings can result in unnecessary workups, prescriptions to avoid sports and other desirable, healthful, or necessary activities, as well as psychological damage.
2. Cardiovascular screening's potential value in actual use is discounted by inaccuracy in diagnosis, and patients who receive a positive test are less likely to pursue further screening or treatment.

Screening tests can be more effective by limiting the testing to relatives of individuals with the disease. This significantly increases the likelihood of disease prevalence in the tested population (50%), thus improving the accuracy of positive predictions. Known as cascade screening, this approach is particularly helpful in families with identified disease-causing mutations and specific phenotypes like LQTS. It can also be applied in cases of sudden unexplained death, using appropriate techniques such as electrocardiographic or genetic testing (Figure 4).

In the risk score model, the baseline hazard of the patient's congenital defect is multiplied by the risk factors to calculate the annual risk of SCD [47].

### SCD of young and the family affected

Immediately after a SCD in a young person, there are various

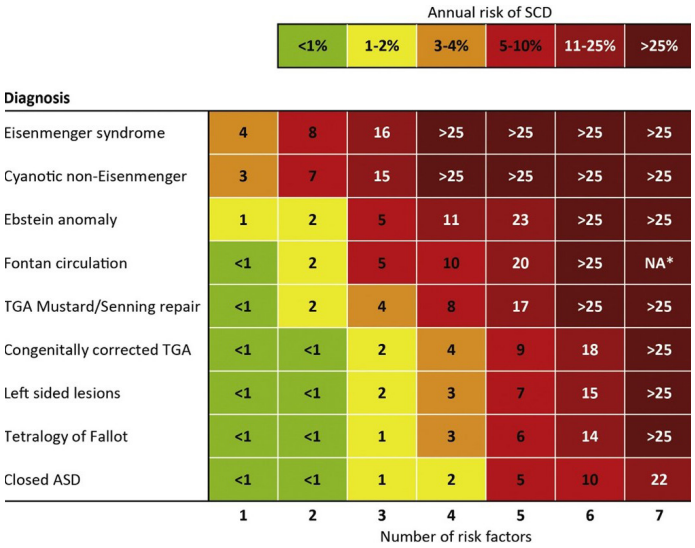


**Figure 4:** The risk score model of 9 congenital lesions at the highest risk of SCD [47].

challenges that need to be addressed concerning the well-being of the surviving family members. Firstly, the ability to conduct a postmortem examination, such as an autopsy, depends on the specific location where the SCD took place. This is because the competence in postmortem cardiac diagnosis and the availability of specialized cardiac examination can vary significantly across different states, counties, and cities. Secondly, there is no standardized approach to evaluating the hearts of first-degree relatives after an SCD event. Without a universally accepted standard of care for investigating families affected by SCD, physicians can have different responses. These responses can range from simply asking about symptoms to performing a wide range of noninvasive and, in some cases, invasive cardiac tests on everyone. Furthermore, these tests may need to be repeated at frequent intervals. Thirdly, the current state of postmortem genetic testing, also known as the molecular autopsy, is uncertain [48]. This uncertainty arises from the development of new genetic technologies and an increasingly nuanced understanding of the significance of different genetic markers and point mutations. As a result, the approach to postmortem genetic testing can vary greatly. Additionally, using genetic testing on the SCD patient, which can be a valuable and specific tool for clinical investigation when combined with broader familial investigations, often faces challenges related to reimbursement for tests conducted on deceased individuals.

The clinician's ability to provide useful diagnostic information to families of young SCD patients is, therefore, under construction at present. A combination of phenotypic and, in some cases, genotypic information with information obtained from the affected individual and close relatives will be used to provide a specific diagnosis, identify other family members at risk, and provide actionable clinical information of value to survivors.

Currently, there is a lack of agreement regarding the necessary steps for a thorough investigation of a young SCD patient after death and the essential investigations for the surviving first-degree relatives before death. At the very least, guidelines from medical examiner's offices should include the collection of DNA-friendly tissue (such as blood in EDTA, frozen nucleated tissue, or blood spot cards) to allow for genetic testing after death if necessary [49-51]. An echocardiogram, 12-lead ECGs, 24-hour Holter monitors, treadmill stress tests, and an echocardiogram may be appropriate for surviving first-degree relatives based on autopsy findings. It is still unclear whether these investigations should be carried out simultaneously or if a sequential approach starting with a molecular autopsy of the deceased would be more cost-effective.

## Classification of Risks Involved in Specific Individual Diseases

There is a small but significant portion of young individuals (between 12% and 18%) who suffer from SCD already have a known cardiac condition. Once a specific high-risk diagnosis has been confirmed, the presence of arrhythmia symptoms or other indicators can be used to identify subgroups that are at higher risk for the development of SCD. To stratify patients' risk, it needs to be based on conditions that are prevalent and well-researched in different groups of patients. Patients with HCM and channelopathies like long QT syndrome, for whom clear guidelines have been established, are particularly at risk. Studies on risk stratification strategies for young populations in SCD-predisposing diseases rely primarily on retrospective designs [52]. Moreover, many variables identified as associated with increased risk in patients are also associated with each other. Due to these factors, risk stratification frameworks used for young individuals with SCD are less explicitly prescriptive than those used in adult cardiology that are validated risk assessment tools. The assessment of risk factors should therefore be conducted cautiously, in conjunction with an individual's clinical assessment and judgment.

## Preliminary Prevention of SCD

For patients deemed to be at a heightened risk of SCD, it may be fitting to contemplate the insertion of an ICD for primary prevention. In the context of ischemic cardiomyopathy and left ventricular dysfunction, where the benefits of ICD implantation are clearly demonstrated, this concept has long been widely acknowledged in adult populations. Risk-to-reward ratios for ICDs in children with SCD-predisposing conditions and syndromes are not very well established. When considering the risks associated with ICDs, it is evident that children experience a relatively elevated occurrence of complications linked to the devices, including a higher frequency of inappropriate shocks, malfunctions in the leads, and difficulties in placing the ICD due to the size and anatomy of the heart [53]. On the other hand, when considering the potential advantages of primary prophylaxis, children may experience relatively smaller benefits from ICD implantation. Specifically, the occurrence of sudden death related to CHD and various arrhythmic cardiomyopathies is significantly lower in children compared to adults who find ICDs beneficial (for example, adults with tetralogy of Fallot have an annual rate of 0.1% to 0.2%). Guidelines regarding the criteria for ICD implantation for primary prevention in children and young individuals with CHD and other SCD-predisposing conditions are more flexible compared to those applied for adults with acquired heart disease. Nevertheless, due to the challenges associated with ICDs in this population, pediatric clinicians who specialize in patients at risk for SCD generally adopt cautious decision-making algorithms to determine whether these devices should be implanted or not [2].

## Resuscitation and SCD

Regrettably, there is typically no discussion regarding the connection between the epidemiology and clinical diagnosis of conditions that predispose individuals to SCD, along with the science and practice of resuscitation. Consequently, the literature and knowledge base in these two fields largely do not overlap, despite their strong association with the topic of defibrillation. Given the low survival rates of out-of-hospital cardiac arrest (OHCA), all aspects of resuscitation science can be considered relevant to a comprehensive approach to preventing and managing SCD in young individuals. Understanding the clinical characteristics of SCD in the young informs strategies for resuscitation

and the provision of services in the community [53]. Conversely, continually improving and assessing the effectiveness and availability of bystander and EMS response to SCD enhances survival rates and influences the risk-benefit calculations necessary for making clinical decisions for patients with predisposing conditions for SCD.

## Sudden Cardiac Arrest (SCA)

Due to its precision, SCA is a more effective way to resuscitate someone than SCD. SCA is the result of the electrical or mechanical malfunction of the heart, leading to a loss of consciousness and sudden death [54]. This description emphasizes the main cardiovascular reasons and does not indicate a particular result. Earlier definitions like "nontraumatic death happening abruptly or within 24 hours after the start of sudden symptoms" are more accurately referred to as sudden unexpected death, as the underlying causes are wider, and the specified outcome is death.

### Management principles and pathophysiology of SCA

OHCA can cause ventricular fibrillation (VF), asystole, pulseless electric activity, and asystole in young people. According to epidemiological studies, asystole is more common in children with OHCA than ventricular arrhythmias. However, the population studied here often suffers from VF as the primary arrhythmia in SCA due to comorbid conditions, intercurrent illnesses, drowning, and suffocation.

The pathogenesis of SCA caused by pulseless ventricular tachycardia and VF is time sensitive, characterized by 3 stages distinguished by heart rhythm and metabolic effects of reduced blood flow and lack of oxygen. These stages determine suitable treatments and forecast the likelihood of survival and neurological impairment. The primary electrical phase lasts approximately 4 minutes and is identified by the existence of treatable heart rhythms. Throughout this timeframe, the heart responds to defibrillation, as evidenced by the results of ICD placement and implementation of public-access defibrillation initiative investigations [55, 56].

During the circulatory stage, tissue hypoxemia becomes apparent, and asystole emerges. It is essential to administer cardiopulmonary resuscitation (CPR) to ensure oxygen supply during this stage. The efficacy of defibrillation is reduced, but it can be improved by administering epinephrine before the shock and performing effective CPR. The metabolic stage begins approximately 10 minutes after SCA, characterized by asystole, worsening hypoxia, and the presence of circulating metabolic factors that lead to cell death and dysfunction of vital organs. Survival is unlikely during this stage and is often accompanied by severe impairment in functionality [57].

### Components of CPR

Successful CPR involves 4 components: chest compression, defibrillation, ventilation, and pharmacological agents. Despite their importance, early defibrillation and effective chest compression have been shown the most clearly to increase survival rates in children and adults.

#### Chest compression

By causing intrathoracic pressure changes and by applying direct cardiac compression, chest compressions cause forward blood flow. In standard CPR, the cardiac output is 30% to 40% of normal; cerebral flow is as high as 60%, while myocardial flow is substantially lower at 10% to 30%. To restore cerebral function, cerebral perfusion pressure must be adequate, whereas cardiac resuscitation requires adequate coronary perfusion pressure [58].

During CPR, the pressure of blood flow increases for about 5 to 7 compressions but decreases quickly during pauses. As a result, the time available for blood flow to the heart and brain is reduced when ventilation is paused. Effective CPR also necessitates the chest to fully recoil, allowing blood to return to the chest cavity [59-61]. Excessive compression rates can negatively impact blood flow to the heart and the depth of compressions. Overall, compression fractions below 80% are linked to lower chances of survival, which is why current guidelines emphasize the importance of short and infrequent pauses.

#### Defibrillation

The prompt use of defibrillation is a critical element in improving the likelihood of survival from VF cardiac arrest. Initially, it was believed that the electrical current stopped fibrillation by polarizing a significant portion of the heart muscle. However, it is now recognized that preventing the recurrence of fibrillation after defibrillation is just as important [62]. The effectiveness of defibrillation relies on the amount of current administered, the shape of the waveform, and the impedance of the chest. Biphasic waveforms have demonstrated great success in terminating VF and have become the preferred option in clinical practice, surpassing monophasic devices [63].

#### Airway management and ventilation

Initially, assisted breathing was deemed necessary for effective revival. However, if a heart attack occurs suddenly, there is enough oxygen in the blood vessels to allow for a period of compression without breathing assistance. Applying pressure to the chest during ventilation can raise pressure inside the chest and potentially reduce the flow of blood from the heart and the pressure needed for blood to reach the heart muscles [64]. The ideal ratio of chest compressions to breathing has not yet been established, but recent recommendations have shown a growing focus on prioritizing chest compressions.

#### Pharmacological agents

Resuscitation efforts frequently involve the use of vasopressive and antiarrhythmic medications. However, no drug has been proven to increase long-term survival after a cardiac arrest in prospective trials. While it is common to administer epinephrine during cardiac arrest, its effectiveness is still a subject of discussion. Although epinephrine has been demonstrated to enhance the return of spontaneous circulation, there is no proof to support improved long-term survival [65]. Vasopressin has been explored as a potential alternative, but comparisons between epinephrine, vasopressin, and a placebo have not revealed any superiority in terms of hospital discharge or long-term survival. Due to the limitations of current research, further clinical trials are necessary to arrive at definitive conclusions regarding survival outcomes [2].

### Importance of effective and high-quality CPR

The importance of effective CPR in determining survival has become evident. In both emergency medical services and hospital settings, the performance of CPR is often less than optimal. Key indicators of CPR quality include maintaining the correct rate and depth of chest compressions, ensuring proper chest recoil, the proportion of time devoted to chest compressions during CPR, and maintaining the appropriate ventilation rate [66]. Numerous studies have demonstrated the positive impact on outcomes when these variables are assessed and tracked.

The primary focus now lies on chest compression, and research on both animals and humans suggests that survival rates are comparable when using chest compression alone. In 2008, the American Heart

Association (AHA) approved the use of chest compression-only CPR for bystanders who witness a collapse. Subsequently, in 2010, the AHA updated the CPR protocol from Airway–Breathing–Chest Compression to Chest Compression–Airway–Breathing [67]. This modification was based on evidence demonstrating the effectiveness of bystander CPR and the importance of increasing its frequency and quality, while also removing obstacles that prevent laypersons from performing CPR. Moreover, survival rates for OHCA have risen by 40% [68, 69]. A recent extensive study conducted in Japan revealed that the widespread adoption of chest compression-only CPR by bystanders led to a significant enhancement in neurologically favorable survival.

## Techniques of CPR for Young Children

Babies and children follow the same basic physiological principles as adults when it comes to CPR. However, there are variations in the technique to account for differences in age-related body size, elasticity of the chest wall, and primary causes of cardiac arrest. As a result, the AHA guidelines propose different compression-ventilation ratios and shallower compression depth for infants [70]. Chest compression–only CPR has proven to be effective as conventional CPR for children with presumed cardiac arrest.

## Chain and Chances of Survival

During cardiac arrest, survival depends on the prompt initiation of treatment, with a 10% decrease in survival probability for each minute delay in the initiation of CPR. In the field, resuscitation principles have been deployed based on the chain of survival construct [71].

Survival rates for OHCA in the United States vary greatly. A study conducted across 10 North American locations found that survival rates ranged from 7.7% to 39.9%. While certain factors such as patient demographics, education, and health status contribute to these differences, it is likely that community and healthcare system elements play a significant role [72]. Numerous communities have made efforts to improve their survival statistics. As a result, they have witnessed a doubling or tripling of survival rates for OHCA, providing valuable insights for other communities seeking to enhance their systems. Key factors for success include strong leadership, active community involvement, a well-supported EMS system, and hospitals equipped to deliver exceptional post-arrest care [73].

## Leadership-fostering a Culture for Outstanding Performance

In the high-achieving communities, the leaders have fostered a culture of outstanding performance, incorporating ongoing data gathering, examination, and documentation to assess the advancements made in the execution of innovative tactics [74]. Instances of triumphant novel methods have involved modifying CPR guidelines to reduce interruptions in chest compressions during defibrillation, providing uninterrupted chest compressions for extended periods, postponing ventilations, and intubation, and utilizing impedance threshold devices.

## Community Participation and Responsibility

Community participation and responsibility are crucial for the initial steps in the chain (prompt EMS activation, prompt CPR, and prompt defibrillation). Administering CPR as a bystander enhances the heart's reaction to defibrillation and significantly increases the chances of survival upon hospital discharge while also improving neurological results [75]. Unfortunately, CPR training has been received by just a mere 4% of the American population, and out of the 15% to 20% of out-of-hospital cardiac arrests, only 20% to 30% receive CPR or defibrillation from bystanders.

For years, the AHA and the American Red Cross have been backing CPR instruction, but teaching CPR courses to many responders is both costly and ineffective, especially in rural areas and communities with a significant Hispanic and black population. To ensure that everyone in society receives training, other options can be considered, such as incorporating CPR instruction in schools or making it a mandatory step for activities like obtaining a driver's license. The World Health Organization and the AHA have given their endorsement to school-based CPR training [76-79]. Currently, 27 states have passed laws to either mandate or support CPR training as a requirement for graduation.

## Creation of AEDs for Location of Public Access Defibrillation

Over the last two decades, the creation of AEDs has resulted in the formation of Public Access Defibrillation locations, where individuals with minimal training can utilize defibrillators [80]. Selected areas, including government buildings, airports, transportation centers, and casinos, have shown positive advancements in outcomes. The Public Access Defibrillation Trial illustrated a twofold increase in the survival rate of adults with satisfactory neurological function when they were revived using CPR and AEDs, as opposed to CPR alone [81-83].

Organizational structure is necessary for Public Access Defibrillation sites to maintain their effectiveness. Public Access Defibrillation initiatives that have appropriate leadership and place AEDs in high-risk areas while ensuring ongoing maintenance have a cost ranging from $30,000 to $100,000 per quality-adjusted life-year. However, if any of these essential elements are missing, the cost per QALY can significantly increase [84]. AED programs implemented in schools receive strong support due to the significance of sports events in that environment and concerns about preventing sudden death among athletes. Despite the infrequency of such incidents, school programs seem to be effective.

## Hospitals and Post-arrest Care

Hospitals play a crucial role in providing early care after a successful resuscitation, marking the final stage in the survival process. Post–cardiac arrest syndrome is a complex clinical condition that involves various pathophysiological mechanisms. Myocardial dysfunction, neurological damage, systemic ischemic injury, and reperfusion injury necessitate prompt evaluation and treatment to stabilize the patient and prevent additional harm [85-87]. The development of systemic inflammatory and septic shock syndromes can also impact the patient's ability to recover without disabilities. A multidisciplinary approach is employed, focusing on providing hemodynamic and ventilatory support, preserving neurological function, and preventing further injury and associated complications.

The aim of targeted temperature management is to slow down the pathophysiologic events and biochemical systems that lead to cellular damage. Initial controlled experiments used targeted temperatures ranging from 32 °C to 34 °C and showed improved neurological outcomes for patients experiencing VF arrests. However, uncertainties persist regarding the ideal target temperature, specific patient groups, duration of hypothermia, and methods for inducing, maintaining, and reversing it [88, 89]. The neurological outcomes of young patients with OHCA were not disparate after one year in a recent randomized trial conducted across multiple centers. The use of targeted temperature management remains a viable treatment option for patients under 18 years of age, has been quickly integrated into standard clinical practice, and is still recommended for patients with shockable rhythms despite

this apparently negative finding. Those patients with underlying CHD or reversible diseases may be eligible for extracorporeal membrane oxygenation, if existing protocols, personnel, and equipment are available and established [90-93]. Children who have experienced a cardiac arrest in-hospital may benefit from extracorporeal membrane oxygenation following prolonged CPR, no data is available to support its use in OHCA where cardiovascular support is markedly delayed [94-98].

## Conclusions

In the last ten years, there has been an increase in available information to assist in identifying and treating children and young adults who are at risk of SCD. Although the occurrence of this issue is rare, its impact is significant. A systematic method can be employed to pinpoint areas for preventative measures and treatment. By arranging and contextualizing the pertinent research in each of these fields, notable gaps in understanding can be more easily recognized. Pressing inquiries that need to be answered encompass the following [2].

If we know SCD epidemiology in the young, can we use it to develop effective interventions? Should ECG screenings be used universally to identify young people at risk for SCD or should they focus on certain subgroups?

What is the proper method for conducting an evaluation after SCD, for both the deceased individual and their surviving family members? Additionally, what is the significance of genetic testing after death (also known as molecular autopsy)?

Can we lower the occurrence of SCD among young individuals by implementing preventative lifestyle limitations? Which specific conditions could benefit from this approach, what activities should be restricted, and how can we measure the impact of these interventions?

What is the most effective primary prevention ICD design and implant technique for young patients? Does improved design and implant technique improve the risk-to-benefit ratio in children and make them a more effective technology for high-risk patients?

Is it possible to modify the barriers that prevent the community from providing better resuscitation for the young? What can be done to improve survival outcomes after OHCA in the young through better EMS and post-resuscitation care?

The management of SCD in young individuals involves both proactive measures to reduce the risk and effective response to cardiac arrest by the community. These objectives can be achieved through various means, such as implementing screening programs to identify high-risk patients, evaluating the risk level of individuals with SCD-predisposing conditions, providing appropriate preventative treatment and lifestyle advice, ensuring widespread availability of resuscitation expertise and advanced technology, as well as offering diagnostic assessment and follow-up care for affected families. Establishing and utilizing a nationwide registry specifically for SCD in young individuals will serve as a valuable data source, enabling the exploration of critical questions in this field.

## Acknowledgements

None.

## Conflict of Interest

None.

### References

1. Willinger M, James LS, Catz C (1991) Defining the sudden infant death syndrome (SIDS): deliberations of an expert panel convened by the National Institute of Child Health and Human Development. Pediatr Pathol 11: 677–684. https://doi.org/10.3109/15513819109065465
2. Ackerman M, Atkins DL, Triedman JK (2016) Sudden cardiac death in the young. Circulation 133: 1006-1026. https://doi.org/10.1161/CIRCULATIONAHA.115.020254
3. Erickson CC, Salerno JC, Berger S, Campbell R, Cannon B, et al. (2021) Sudden death in the young: information for the primary care provider. Pediatrics 14. https://doi.org/10.1542/peds.2021-052044
4. Finocchiaro G, Radaelli D, D'Errico S, Papadakis M, Behr ER, et al. (2023) Sudden cardiac death among adolescents in the United Kingdom. J Am Coll Cardiol 81: 1007-1017. https://doi.org/10.1016/j.jacc.2023.01.041
5. Children Dying Preventable Deaths from Congenital Heart Disease. [https://medicalxpress.com/news/2016-12-children-dying-deaths-congenital-heart.html] [Accessed December 28, 2023] https://medicalxpress.com/news/2016-12-children-dying-deaths-congenital-heart.html
6. Moon RY, Task Force on Sudden Infant Death Syndrome (2011) SIDS and other sleep-related infant deaths: expansion of recommendations for a safe infant sleeping environment. Pediatrics 128: e1341-1367. https://doi.org/10.1542/peds.2011-2284
7. Atkins DL, Berger S, Duff JP, Gonzales JC, Hunt EA, et al. (2015) Part 11: pediatric basic life support and cardiopulmonary resuscitation quality: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 132: S519-525. https://doi.org/10.1161/cir.0000000000000265
8. De Caen AR, Berg MD, Chameides L, Gooden CK, Hickey RW, Scott HF, et al. (2015) Part 12: pediatric advanced life support: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care (reprint). Pediatrics 136: S176-195. https://doi.org/10.1161/CIR.0000000000000266
9. Neumar RW, Shuster M, Callaway CW, Gent LM, Atkins DL, et al. (2015) Part 1: executive summary: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 132: S315-367. https://doi.org/10.1161/cir.0000000000000252
10. Link MS, Myerburg RJ, Estes NAM (2015). Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 12: emergency action plans, resuscitation, cardiopulmonary resuscitation, and automated external defibrillators: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e334-338. https://doi.org/10.1161/cir.0000000000000248
11. Epstein AE, DiMarco JP, Ellenbogen KA, Estes NM, Freedman RA, et al. (2012). 2012 ACCF/AHA/HRS focused update incorporated into the ACCF/AHA/HRS 2008 guidelines for device-based therapy of cardiac rhythm abnormalities: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Heart Rhythm Society. Circulation 127: e283-e352. https://doi.org/10.1161/cir.0b013e318276ce9b
12. Kumar A, Avishay DM, Jones CR, Shaikh JD, Kaur R, et al. (2021) Sudden cardiac death: epidemiology, pathogenesis and management. Rev Cardiovasc Med 22: 147-158. https://doi.org/10.31083/j.rcm.2021.01.207
13. Maron BJ, Udelson JE, Bonow RO, Nishimura RA, Ackerman MJ, et al. (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 3: hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy and other cardiomyopathies, and myocarditis: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e273-80. https://doi.org/10.1161/cir.0000000000000239
14. Ackerman MJ, Zipes DP, Kovacs RJ, Maron BJ (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 10: the cardiac channelopathies: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e326-9. https://doi.org/10.1161/cir.0000000000000246
15. Priori SG, Wilde AA, Horie M, Cho Y, Behr ER, et al. (2013) HRS/EHRA/APHRS expert consensus statement on the diagnosis and management of patients with inherited primary arrhythmia syndromes: document endorsed by HRS, EHRA, and APHRS in May 2013 and by ACCF, AHA, PACES, and AEPC in June 2013. Heart Rhythm 10: 1932-63. https://doi.org/10.1016/j.hrthm.2013.05.014
16. Vetter VL, Elia J, Erickson C, Berger S, Blum N, et al. (2008) Cardiovascular monitoring of children and adolescents with heart disease receiving stimulant drugs: a scientific statement from the American Heart Association Council on Cardiovascular

Disease in the Young Congenital Cardiac Defects Committee and the Council on Cardiovascular Nursing. Circulation 117: 2407-23. https://doi.org/10.1161/circulationaha.107.189473

17. Estes NM, Kovacs RJ, Baggish AL, Myerburg RJ (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 11: drugs and performance-enhancing substances: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e330-3. https://doi.org/10.1161/cir.0000000000000247

18. Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, et al. (2007) Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. Circulation 115: 1643-55. https://doi.org/10.1161/CIRCULATIONAHA.107.181423

19. Maron BJ, Friedman RA, Kligfield P, Levine BD, Viskin S, et al. (2014) Assessment of the 12-Lead Electrocardiogram as a Screening Test for Detection of Cardiovascular Disease in Healthy General Populations of Young People (12–25 Years of Age) A Scientific Statement From the American Heart Association and the American College of Cardiology. J Am Coll Cardiol 64: 1479-514. https://doi.org/10.1016/j.jacc.2014.05.006

20. Levine BD, Baggish AL, Kovacs RJ, Link MS, Maron MS, et al. (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 1: classification of sports: dynamic, static, and impact: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e262-6. https://doi.org/10.1161/cir.0000000000000237

21. Maron BJ, Zipes DP, Kovacs RJ (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: preamble, principles, and general considerations: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e256-61. https://doi.org/10.1161/CIR.0000000000000236

22. Van Hare GF, Ackerman MJ, Evangelista JA, Kovacs RJ, Myerburg RJ, et al. (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 4: congenital heart disease: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e281-91. https://doi.org/10.1161/cir.0000000000000240

23. Zipes DP, Link MS, Ackerman MJ, Kovacs RJ, Myerburg RJ, et al. (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 9: arrhythmias and conduction defects: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e315-25. https://doi.org/10.1161/cir.0000000000000245

24. Maron BJ, Murphy CJ, Haas TS, Ahluwalia A, Garberich RF (2014) Strategies for assessing the prevalence of cardiovascular sudden deaths in young competitive athletes. Int J Cardiol 173: 369-72. https://doi.org/10.1016/j.ijcard.2014.02.021

25. Chugh SS, Jui J, Gunson K, Stecker EC, John BT, et al. (2004) Current burden of sudden cardiac death: multiple source surveillance versus retrospective death certificate-based review in a large US community. J Am Coll Cardiol 44: 1268-75. https://doi.org/10.1016/j.jacc.2004.06.029

26. Molander NI (1982) Sudden natural death in later childhood and adolescence. Arch Dis Child 57: 572-6. https://doi.org/10.1136/adc.57.8.572

27. Gerein RB, Osmond MH, Stiell IG, Nesbitt LP, Burns S (2006) What are the etiology and epidemiology of out-of-hospital pediatric cardiopulmonary arrest in Ontario, Canada? Acad Emerg Med 13: 653-8. https://doi.org/10.1197/j.aem.2005.12.025

28. Puranik R, Chow CK, Duflou JA, Kilborn MJ, McGuire MA (2005) Sudden death in the young. Heart Rhythm 2: 1277-82. https://doi.org/10.1016/j.hrthm.2005.09.008

29. Chugh SS, Reinier K, Balaji S, Uy-Evanado A, Vickers C, et al. (2009) Population-based analysis of sudden death in children: The Oregon Sudden Unexpected Death Study. Heart Rhythm 6: 1618-22. https://doi.org/10.1016/j.hrthm.2009.07.046

30. Park CB, Do Shin S, Suh GJ, Ahn KO, Cha WC, et al. (2010) Pediatric out-of-hospital cardiac arrest in Korea: a nationwide population-based study. Resuscitation 81: 512-7. https://doi.org/10.1016/j.resuscitation.2009.11.022

31. Papadakis M, Sharma S, Cox S, Sheppard MN, Panoulas VF, et al. (2009) The magnitude of sudden cardiac death in the young: a death certificate-based review in England and Wales. Europace 11: 1353-8.

32. Hendrix A, Vaartjes I, Mosterd A, Reitsma JB, Doevendans PA, Grobbee DE, et al. (2010) Regional differences in incidence of sudden cardiac death in the young. Neth J Med 68: 274-9.

33. Winkel BG, Holst AG, Theilade J, Kristensen IB, Thomsen JL, et al. (2011) Nationwide study of sudden cardiac death in persons aged 1–35 years. Eur Heart J 32: 983-90. https://doi.org/10.1093/eurheartj/ehq428

34. Margey R, Roy A, Tobin S, O'Keane CJ, McGorrian C, et al. (2011) Sudden cardiac death in 14-to 35-year olds in Ireland from 2005 to 2007: a retrospective registry. Europace 13: 1411-8. https://doi.org/10.1093/europace/eux258

35. Winkel BG, Risgaard B, Sadjadieh G, Bundgaard H, Haunsø S, et al. (2014) Sudden cardiac death in children (1–18 years): symptoms and causes of death in a nationwide setting. Eur Heart J 35: 868-75. https://doi.org/10.1093/eurheartj/eht509

36. Bardai A, Berdowski J, Van Der Werf C, Blom MT, Ceelen M, et al. (2011) Incidence, causes, and outcomes of out-of-hospital cardiac arrest in children: a comprehensive, prospective, population-based study in the Netherlands. J Am Coll Cardiol 57: 1822-8. https://doi.org/10.1016/j.jacc.2010.11.054

37. Meyer L, Stubbs B, Fahrenbruch C, Maeda C, Harmon K, et al. (2012) Incidence, causes, and survival trends from cardiovascular-related sudden cardiac arrest in children and young adults 0 to 35 years of age: a 30-year review. Circulation 126: 1363-72. https://doi.org/10.1161/circulationaha.111.076810

38. Corrado D, Basso C, Schiavon M, Thiene G (1998) Screening for hypertrophic cardiomyopathy in young athletes. N Engl J Med 339: 364-9. https://doi.org/10.1056/nejm199808063390602

39. Thompson PD (2009) Preparticipation screening of competitive athletes: seeking simple solutions to a complex problem. Circulation 119: 1072-4. https://doi.org/10.1161/circulationaha.108.843862

40. Steriotis AK, Nava A, Rigato I, Mazzotti E, Daliento L, et al. (2013) Noninvasive cardiac screening in young athletes with ventricular arrhythmias. Am J Cardiol 111: 557-62. https://doi.org/10.1016/j.amjcard.2012.10.044

41. Toresdahl BG, Rao AL, Harmon KG, Drezner JA (2014) Incidence of sudden cardiac arrest in high school student athletes on school campus. Heart Rhythm 11: 1190-4. https://doi.org/10.1016/j.hrthm.2014.04.017

42. Kaltman JR, Thompson PD, Lantos J, Berul CI, Botkin J, et al. (2011) Screening for sudden cardiac death in the young: report from a national heart, lung, and blood institute working group. Circulation 123: 1911-8. https://doi.org/10.1161/circulationaha.110.017228

43. Campbell R, Berger S, Ackerman MJ, Morrow WR, Jenkins K, et al. (2012) Pediatric sudden cardiac arrest. Pediatrics 129: e1094-102. https://doi.org/10.1097/mop.0b013e328357a7c3

44. Semsarian C, Sweeting J, Ackerman MJ (2015) Sudden cardiac death in athletes. BMJ 18: 350. https://doi.org/10.1136/bmj.h1218

45. Ackerman M, Atkins DL, Triedman JK (2016) Sudden cardiac death in the young. Circulation 133: 1006-26. https://doi.org/10.1161/circulationaha.115.020254

46. Steinvil A, Chundadze T, Zeltser D, Rogowski O, Halkin A, et al. (2011) Mandatory electrocardiographic screening of athletes to reduce their risk for sudden death: proven fact or wishful thinking?. J Am Coll Cardiol 57: 1291-6. https://doi.org/10.1016/j.jacc.2010.10.037

47. Maron BJ, Friedman RA, Kligfield P, Levine BD, Viskin S, et al. (2014) Assessment of the 12-lead ECG as a screening test for detection of cardiovascular disease in healthy general populations of young people (12–25 years of age) a scientific statement from the American Heart Association and the American College of Cardiology. Circulation 130: 1303-34. https://doi.org/10.1016/j.jacc.2014.05.006

48. Hazinski MF, Nolan JP, Aickin R, Bhanji F, Billi JE, et al. (2015) Part 1: executive summary: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 132: S2-39. https://doi.org/10.1161/cir.0000000000000270

49. Vehmeijer JT, Koyak Z, Leerink JM, Zwinderman AH, Harris L, et al. (2021) Identification of patients at risk of sudden cardiac death in congenital heart disease: the PRospEctiVE study on implaNTable cardIOverter defibrillator therapy and suddeN cardiac death in Adults with Congenital Heart Disease (PREVENTION-ACHD). Heart Rhythm 18(5): 785-92. https://doi.org/10.1016/j.hrthm.2021.01.009

50. Anderson ML, Cox M, Al-Khatib SM, Nichol G, Thomas KL, et al. (2014) Rates of cardiopulmonary resuscitation training in the United States. JAMA Intern Med 174: 194-201. https://doi.org/10.1001/jamainternmed.2013.11320

51. Richardson P (1996) Report of the 1995 World Health Organization/International Society and Federation of Cardiology Task Force on the definition and classification of cardiomyopathies. Circulation 93: 841-2. https://doi.org/10.1161/01.cir.93.5.841

52. Maron BJ, Haas TS, Murphy CJ, Ahluwalia A, Rutten-Ramos S (2014) Incidence and causes of sudden death in US college athletes. J Am Coll Cardiol 63: 1636-43. https://doi.org/10.1016/j.jacc.2014.01.041

53. Khairy P, Landzberg MJ, Gatzoulis MA, Lucron H, Lambert J, et al. (2004) Value of programmed ventricular stimulation after tetralogy of fallot repair: a multicenter study. Circulation 109: 1994-2000. https://doi.org/10.1161/01.cir.0000126495.11040.bd

54. Khairy P, Aboulhosn J, Gurvitz MZ, Opotowsky AR, Mongeon FP, et al. (2010) Arrhythmia burden in adults with surgically repaired tetralogy of Fallot: a multi-institutional study. Circulation 122: 868-75. https://doi.org/10.1161/circulationaha.109.928481

55. Klein GJ, Bashore TM, Sellers TD, Pritchett EL, Smith WM, et al. (1979) Ventricular fibrillation in the Wolff-Parkinson-White syndrome. New Engl J Med 301: 1080-1085. https://doi.org/10.1056/nejm197911153012003

56. Klein GJ, Prystowsky EN, Yee R, Sharma AD, Laupacis A (1989) Asymptomatic Wolff-Parkinson-White. Should we intervene?. Circulation 80: 1902-5. https://doi.org/10.1161/01.CIR.80.6.1902

57. Leitch JW, Klein GJ, Yee R, Murdock C (1990) Prognostic value of electrophysiology testing in asymptomatic patients with Wolff-Parkinson-White pattern. Circulation 82: 1718-23. https://doi.org/10.1161/01.CIR.82.5.1718

58. Cohen MI, Triedman JK, Cannon BC, Davis AM, Drago F, et al. (2012) PACES/HRS expert consensus statement on the management of the asymptomatic young patient with a Wolff-Parkinson-White (WPW, Ventricular Preexcitation) electrocardiographic pattern. Heart Rhythm 9: 1006-1024. https://doi.org/10.1016/j.hrthm.2012.03.050

59. Khairy P, Harris L, Landzberg MJ, Viswanathan S, Barlow A, et al. (2008) Implantable cardioverter-defibrillators in tetralogy of Fallot. Circulation 117: 363-70. https://doi.org/10.1161/circulationaha.107.726372

60. Nieminen HP, Jokinen EV, Sairanen HI (2007) Causes of late deaths after pediatric cardiac surgery: a population-based study. J Am Coll Cardiol 50: 1263-71. https://doi.org/10.1016/j.jacc.2007.05.040

61. Verheugt CL, Uiterwaal CS, van der Velde ET, Meijboom FJ, Pieper PG, et al. (2010) Mortality in adult congenital heart disease. Eur Heart J 31: 1220-9. https://doi.org/10.1093/eurheartj/ehq032

62. Nollert G, Fischlein T, Bouterwek S, Böhmer C, Klinner W, et al. (1997) Long-term survival in patients with repair of tetralogy of Fallot: 36-year follow-up of 490 survivors of the first year after surgical repair. J Am Coll Cardio 30: 1374-83. https://doi.org/10.1016/s0735-1097(97)00318-5

63. Murphy JG, Gersh BJ, Mair DD, Fuster V, McGoon MD, et al. (1993) Long-term outcome in patients undergoing surgical repair of tetralogy of Fallot. New Engl J Med 329: 593-599. https://doi.org/10.1056/nejm199308263290901

64. Gatzoulis MA, Balaji S, Webber SA, Siu SC, Hokanson JS, et al. (2000) Risk factors for arrhythmia and sudden cardiac death late after repair of tetralogy of Fallot: a multicentre study. Lancet 356: 975-981. https://doi.org/10.1016/s0140-6736(00)02714-8

65. Silka MJ, Hardy BG, Menashe VD, Morris CD (1998) A population-based prospective evaluation of risk of sudden cardiac death after operation for common congenital heart defects. J Am Coll Cardiol 32: 245-251. https://doi.org/10.1016/s0735-1097(98)00187-9

66. Valente AM, Gauvreau K, Assenza GE, Babu-Narayan SV, Schreier J, et al. (2014) Contemporary predictors of death and sustained ventricular tachycardia in patients with repaired tetralogy of Fallot enrolled in the INDICATOR cohort. Heart 100: 247-53. https://doi.org/10.1136/heartjnl-2013-304958

67. Khairy P, Aboulhosn J, Gurvitz MZ, Opotowsky AR, Mongeon FP, et al. (2010) Arrhythmia burden in adults with surgically repaired tetralogy of Fallot: a multi-institutional study. Circulation 122: 868-875. https://doi.org/10.1161/circulationaha.109.928481

68. Roberts WO, Stovitz SD (2013) Incidence of sudden cardiac death in Minnesota high school athletes 1993–2012 screened with a standardized pre-participation evaluation. J Am Coll Cardiol 62: 1298-12301. https://doi.org/10.1016/j.jacc.2013.05.080

69. Drezner JA, Rogers KJ, Zimmer RR, Sennett BJ (2005) Use of automated external defibrillators at NCAA Division I universities. Med Sci Sports Exerc 37: 1487-92. https://doi.org/10.1249/01.mss.0000177591.30968.d4

70. Corrado D, Thiene G, Nava A, Rossi L, Pennelli N (1990) Sudden death in young competitive athletes: clinicopathologic correlations in 22 cases. Am J Med. 89: 588-596. https://doi.org/10.1016/0002-9343(90)90176-e

71. Corrado D, Basso C, Thiene G (2001) Sudden cardiac death in young people with apparently normal heart. Cardiovas Res 50: 399-408. https://doi.org/10.1016/s0008-6363(01)00254-1

72. Maron BJ (2003) Sudden death in young athletes. New Engl J Med 349: 1064-1075. https://doi.org/10.1161/01.cir.62.2.218

73. Ackerman M, Atkins DL, Triedman JK (2016) Sudden cardiac death in the young. Circulation 133: 1006-1026. https://doi.org/10.1161/CIRCULATIONAHA.115.020254

74. Eckart RE, Scoville SL, Campbell CL, Shry EA, Stajduhar KC, et al. (2004) Sudden death in young adults: a 25-year review of autopsies in military recruits. Ann Inter Med 141: 829-834. https://doi.org/10.7326/0003-4819-141-11-200412070-00005

75. Harmon KG, Asif IM, Maleszewski JJ, Owens DS, Prutkin JM, et al. (2015) Incidence, cause, and comparative frequency of sudden cardiac death in national collegiate athletic association athletes: a decade in review. Circulation 132: 10-9. https://doi.org/10.1161/circulationaha.115.015431

76. Holst AG, Winkel BG, Theilade J, Kristensen IB, Thomsen JL, et al. (2010) Incidence and etiology of sports-related sudden cardiac death in Denmark—implications for preparticipation screening. Heart Rhythm 7: 1365-71. https://doi.org/10.1016/j.hrthm.2010.05.021

77. Solberg EE, Gjertsen F, Haugstad E, Kolsrud L (2010) Sudden death in sports among young adults in Norway. Eur J Cardiovasc Prev Rehabil 17: 337-341. https://doi.org/10.1097/hjr.0b013e328332f8f7

78. Harmon KG, Drezner JA, Maleszewski JJ, Lopez-Anderson M, Owens D, et al. (2014) Pathogeneses of sudden cardiac death in national collegiate athletic association athletes. Circ Arrhythm Electrophysiol 7: 198-204. https://doi.org/10.1161/circep.113.001376

79. de Noronha S, Sharma S, Papadakis M, Desai S, Whyte G, et al. (2009) Aetiology of sudden cardiac death in athletes in the United Kingdom: a pathological study. Heart 95: 1409-1414. https://doi.org/10.1136/hrt.2009.168369

80. Suárez-Mier MP, Aguilera B, Mosquera RM, Sánchez-de-León MS (2013) Pathology of sudden death during recreational sports in Spain. Forensic Sci Int 226: 188-196. https://doi.org/10.1016/j.forsciint.2013.01.016

81. Maron BJ, Chaitman BR, Ackerman MJ, Bayés de Luna A, Corrado D, et al. (2004) Recommendations for physical activity and recreational sports participation for young patients with genetic cardiovascular diseases. Circulation 109: 2807-2816. https://doi.org/10.1161/01.cir.0000128363.85581.e1

82. Pelliccia A, Fagard R, Bjørnstad HH, Anastassakis A, Arbustini E, et al. (2005) Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the Study Group of Sports Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. Eur Heart J 26: 1422-1445. https://doi.org/10.1093/eurheartj/ehi325

83. Lampert R, Olshansky B, Heidbuchel H, Lawless C, Saarel E, et al. (2013) Safety of sports for athletes with implantable cardioverter-defibrillators: results of a prospective, multinational registry. Circulation 127: 2021-2030. https://doi.org/10.1161/circulationaha.112.000447

84. Johnson JN, Ackerman MJ (2012) Competitive sports participation in athletes with congenital long QT syndrome. JAMA 308: 764-765. https://doi.org/10.1001/jama.2012.9334

85. Sakaguchi T, Shimizu W, Itoh H, Noda T, Miyamoto Y, et al. (2008) Age-and genotype-specific triggers for life-threatening arrhythmia in the genotyped long QT syndrome. J Cardiovasc Electrophysiol.19: 794-799. https://doi.org/10.1111/j.1540-8167.2008.01138.x

86. Link MS (2012) Commotio cordis: ventricular fibrillation triggered by chest impact–induced abnormalities in repolarization. Circ Arrhythm Electrophysiol 5: 425-432. https://doi.org/10.1161/circep.111.962712

87. Kumar K, Mandleywala SN, Gannon MP, Estes III NA, Weinstock J, et al. (2017) Development of a chest wall protector effective in preventing sudden cardiac death by chest wall impact (commotio cordis). Clin J sport Med. 27: 26. https://doi.org/10.1097/jsm.0000000000000297

88. Maron BJ, Udelson JE, Bonow RO, Nishimura RA, Ackerman MJ, et al. (2015) Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 3: hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy and other cardiomyopathies, and myocarditis: a scientific statement from the American Heart Association and American College of Cardiology. Circulation 132: e273-280. https://www.ahajournals.org/doi/full/10.1161/CIR.0000000000000239. https://doi.org/10.1097/00005768-200005000-00002

89. Fuller CM (2000) Cost effectiveness analysis of screening of high school athletes for risk of sudden cardiac death. Med Sci Sports Exerc 32: 887-890.

90. Larsen MP, Eisenberg MS, Cummins RO, Hallstrom AP (1993) Predicting survival from out-of-hospital cardiac arrest: a graphic model. Ann Emerg Med 22: 1652-1658. https://doi.org/10.1016/S0196-0644(05)81302-2

91. American Heart Association. Atlas. [https://atlas.heart.org/home] [December 28, 2023]

92. Casa DJ, Almquist J, Anderson SA, Baker L, Bergeron MF, et al. (2013) The inter-association task force for preventing sudden death in secondary school athletics programs: best-practices recommendations. J Athl Train 48: 546-553. https://doi.org/10.4085/1062-6050-48.4.12

93. Physical Activity Guidelines for Americans. U.S. Department of Health and Human Services.

94. Steinberger J, Daniels SR, Eckel RH, Hayman L, Lustig RH, et al. (2009) Progress and challenges in metabolic syndrome in children and adolescents: a scientific statement from the American Heart Association Atherosclerosis, Hypertension, and Obesity in the Young Committee of the Council on Cardiovascular Disease in the Young; Council on Cardiovascular Nursing; and Council on Nutrition, Physical Activity, and Metabolism. Circulation 119: 628-647. https://doi.org/10.1161/circulationaha.108.191394

95. Abrams DJ (2017) How to develop a clinic for sudden cardiac arrest survivors and families of non-survivors. Cardiol Young 27: S3-S9. https://doi.org/10.1017/S104795111600216X

96. Ackerman M, Atkins DL, Triedman JK (2016) Sudden cardiac death in the young. Circulation 133: 1006-1026. https://doi.org/10.1161/CIRCULATIONAHA.115.020254

97. Erickson CC, Salerno JC, Berger S, Campbell R, Cannon B, et al. (2021) Sudden death in the young: information for the primary care provider. Pediatrics 148: e2021052044. https://doi.org/10.1542/peds.2021-052044

98. Finocchiaro G, Radaelli D, D'Errico S, Papadakis M, Behr ER, et al. (2023) Sudden cardiac death among adolescents in the United Kingdom. J Am Coll Cardiol 81: 1007-1017. https://doi.org/10.1016/j.jacc.2023.01.041