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Preparticipation Cardiac Evaluation in Children and Adolescents: International Guidelines and Practical Considerations

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ABSTRACT

Sudden cardiac death (SCD) in children and adolescents participating in sports, although rare, represents a devastating event with significant clinical and social implications. Preparticipation cardiac screening has been proposed as a preventive strategy to identify individuals at risk before they develop life-threatening arrhythmias or cardiac arrest during exercise. Current evidence demonstrates that the leading causes of SCD in young athletes include hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, anomalous coronary arteries, myocarditis, and inherited channelopathies. International guidelines provide divergent recommendations regarding screening strategies. The American Heart Association and the American College of Cardiology advocate a focused history and physical examination without the routine use of electrocardiography (ECG), whereas the European Society of Cardiology endorses the inclusion of a standard 12-lead ECG. More recent consensus statements, such as those from the International Olympic Committee and Fédération Internationale de Football Association, aim to harmonize approaches across countries. While ECG has been shown to increase sensitivity for detecting silent cardiac conditions, concerns remain about false positives, limited specificity, cost-effectiveness, and the need for experienced interpretation. Emerging strategies, including advanced imaging modalities, genetic testing in selected populations, and artificial intelligence-assisted ECG analysis, may enhance risk stratification in the future. This review summarizes the current evidence, highlights key controversies, and discusses future perspectives on preparticipation cardiac screening in children and adolescents involved in sports.

Keywords: Preparticipation cardiac screening, sudden cardiac death, children, adolescents, electrocardiography, cardiovascular risk assessment

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Introduction

Sudden cardiac death (SCD) in young athletes, though infrequent, remains a devastating clinical and social event that continues to draw attention from physicians, families, and policy makers. The estimated incidence is approximately 1 to 2 per 100,000 athletes annually, with variations across regions depending on population characteristics and methods of ascertainment (1,2). The most common underlying causes in children and adolescents include hypertrophic cardiomyopathy (HCM), arrhythmogenic right ventricular cardiomyopathy (ARVC), congenital anomalies of the coronary arteries, myocarditis, and inherited channelopathies such as long QT syndrome (LQTS) and catecholaminergic polymorphic ventricular tachycardia (CPVT). Despite its rarity, the

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psychological impact of sudden death in apparently healthy young athletes is profound, reinforcing the need for effective preventive measures.

Regular sports participation in childhood is associated with improved cardiorespiratory fitness, lower cardiometabolic risk, and better psychological well-being. Accordingly, the primary goal of preparticipation cardiac evaluation is not to exclude children from sports, but to facilitate safe participation by identifying those at increased risk. At the same time, overdiagnosis and unnecessary restriction may lead to avoidable psychosocial and developmental consequences; therefore, a balanced approach is essential.

Preparticipation cardiac screening has emerged as a potential strategy to reduce the risk of exercise-related SCD by identifying occult cardiovascular disease before competitive sports participation. However, the optimal screening approach remains a matter of debate. The American Heart Association (AHA) and the American College of Cardiology (ACC) recommend a targeted 12-element personal and family history and physical examination without routine use of electrocardiography (ECG) (3). In contrast, the European Society of Cardiology (ESC) advocates inclusion of a resting 12-lead ECG based on evidence from the Italian experience showing a reduction in athlete SCD incidence following mandatory ECG screening (2,4). More recently, international governing bodies such as the International Olympic Committee and Fédération Internationale de Football Association have supported harmonized screening approaches that consider regional resources while aiming to maximize sensitivity and specificity (5,6).

This review provides an updated synthesis of the epidemiology, etiology, and current guidelines for preparticipation cardiac screening in children and adolescents participating in sports. In addition, it highlights controversies regarding diagnostic yield, false-positive rates, and cost-effectiveness and discusses emerging strategies, such as genetic testing and artificial intelligence-assisted ECG analysis, that may shape the future of cardiovascular risk assessment in young athletes.

Epidemiology of Sudden Cardiac Death in Young Athletes

The true incidence of SCD in children and adolescents participating in organized sports is difficult to establish due to variations in study methodology, case definitions, and reporting systems. Estimates range from 1 to 2 cases per 100,000 athlete-years, with higher rates reported in competitive athletes compared with the general adolescent population (1,2). Regional differences are also evident: the Italian registry demonstrated a reduction in SCD incidence after the introduction of mandatory ECG-based screening, whereas North American cohorts have reported relatively stable rates when screening is limited to history and physical examination (7,8).

The etiological spectrum of SCD in young athletes is broad, with structural cardiomyopathies and congenital anomalies predominating. HCM remains the most frequent diagnosis in the United States (US), whereas ARVC and anomalous coronary arteries are more prevalent in European series (9,10). Channelopathies, particularly LQTS and CPVT, account for a significant proportion of autopsy-negative cases (11). Myocarditis and premature atherosclerotic coronary artery disease (CAD), though less common, are also recognized causes, especially in older adolescents (12). Table 1 summarizes the most common causes of SCD in child and adolescent athletes.

Etiologies and Risk Factors in Children and Adolescents

As outlined in the epidemiology section, the causes of SCD in young athletes are heterogeneous. A detailed understanding of the associated clinical risk markers is essential for effective preparticipation screening.

Table 1. Common causes of sudden cardiac death in children and adolescent athletes

Category	Examples/notes
Cardiomyopathies	Hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, dilated cardiomyopathy
Congenital anomalies	Anomalous origin of coronary arteries, congenital aortic stenosis, unrecognized congenital heart disease
Primary arrhythmia syndromes (channelopathies)	Long QT syndrome, catecholaminergic polymorphic ventricular tachycardia, Brugada syndrome
Inflammatory/acquired	Myocarditis, Kawasaki disease-related coronary artery lesions
Other causes	Premature atherosclerotic CAD, commotio cordis, undetermined causes at autopsy

CAD: Coronary artery disease

Cardiomyopathies are the most frequent structural cause of SCD. In HCM, risk indicators include a positive family history of premature SCD, exertional syncope, a harsh systolic murmur on examination, and abnormal ECG findings such as deep Q waves or marked repolarization changes. ARVC, more commonly reported in European cohorts, often presents with ventricular arrhythmias, T-wave inversion in right precordial leads, or a history of unexplained palpitations during exercise (9,10).

Congenital coronary anomalies, particularly anomalous origin of the left coronary artery from the right sinus, can precipitate ischemia or malignant arrhythmias during exertion. These conditions often lack objective physical findings, making exertional chest pain or syncope in otherwise healthy athletes an important clinical red flag (10).

Channelopathies such as LQTS, CPVT, and Brugada syndrome frequently underlie autopsy-negative SCD cases. Clinical clues include exertional syncope, unexplained seizures, and a family history of sudden death before the age of 50. Baseline ECG abnormalities -such as prolonged QT interval, bidirectional ventricular tachycardia on exercise testing, or coved-type ST elevations -are key markers when present (1,9).

Acquired causes, such as myocarditis, should be suspected in athletes presenting with recent viral illness, chest pain, or new-onset arrhythmia. Premature CAD, although rare in pediatric patients, may occur in adolescents with significant risk factors, including obesity, smoking, hypertension, and dyslipidemia. Kawasaki disease-related coronary aneurysms represent another important acquired risk in certain populations (13).

Children and adolescents with congenital heart disease (CHD) form another important subgroup that requires careful evaluation before participation in competitive sports. While advances in surgery and interventional cardiology have enabled many patients with repaired CHD to reach adolescence and adulthood with good functional status, residual lesions, arrhythmogenic substrates, and abnormal hemodynamic responses to exercise may persist. The 36th Bethesda Conference Guidelines provide detailed criteria for participation, stratified by the specific lesion, surgical repair status, and arrhythmic risk (14). For example, individuals with mild, repaired ventricular septal defects may be cleared for all sports, whereas those with severe pulmonary hypertension or cyanotic CHD remain restricted. Recognizing these complexities is crucial in tailoring safe and individualized advice for young athletes with CHD.

Risk is also modified by the type and intensity of sport participation. Contemporary AHA/ACC recommendations classify sports according to their dynamic (isotonic) and static (isometric) components, recognizing that high-dynamic and high-static activities impose different hemodynamic loads in specific cardiac conditions (15). This framework is helpful when counselling young athletes with cardiomyopathies or CHD, as both the underlying lesion and the expected cardiovascular demands of the sport must be considered. A simplified overview of this classification, with common examples of pediatric and adolescent sports, is provided in Table 2.

Finally, extrinsic and lifestyle factors may exacerbate the risk in predisposed individuals. The use of stimulant medications or performance-enhancing substances, dehydration, electrolyte imbalance, and extreme endurance

Table 2. Simplified classification of sports according to dynamic and static components in children and adolescents

Category	Hemodynamic profile	Typical sports (children/ adolescents)	Practical considerations in cardiovascular disease
Low dynamic/low static	Minimal increase in heart rate and blood pressure	Bowling, golf, yoga, recreational walking	Usually acceptable in most cardiac conditions if stable
Moderate dynamic/low-moderate static	Moderate volume load, modest pressure load	Recreational cycling, doubles tennis, volleyball	Caution in moderate/severe valvular disease or significant arrhythmias
High dynamic/low static (endurance)	High volume load, marked increase in heart rate and cardiac output	Distance running, competitive swimming, football/soccer, basketball	Potentially problematic in cardiomyopathies, pulmonary hypertension, complex CHD
Low-moderate dynamic/ high static (strength/ power)	Predominantly pressure load, marked BP elevations	Weightlifting, wrestling, gymnastics, judo	Avoid or restrict in severe aortic stenosis, uncontrolled hypertension, aortopathy
High dynamic/high static (mixed/combat)	High volume and pressure load, intense sympathetic activation	Competitive rowing, ice hockey, handball, high-level martial arts	Highest cardiovascular demand; often restricted in high-risk cardiomyopathies and complex CHD

CHD: Congenital heart disease, BP: Blood pressure

training have all been associated with arrhythmic vulnerability in susceptible athletes (13,16,17). Recognizing these risk markers in conjunction with a careful clinical history and examination enhances the diagnostic yield of preparticipation screening. A comprehensive summary of etiologies and their associated clinical red flags is presented in Table 3.

Screening Modalities

Clinical History

A thorough medical history is the cornerstone of preparticipation screening. The AHA/ACC recommends a structured 12-element history, which includes questions on exertional chest pain, syncope, palpitations, unexplained seizures, and family history of premature sudden death or cardiomyopathy (3) (Table 4). Identifying red flags from history alone can help prioritize athletes for further testing. In many reported cases of athlete SCD, symptoms such as exertional syncope or chest discomfort were present but were not adequately investigated (18).

Physical Examination

Physical examination complements the clinical history, though its sensitivity for detecting silent cardiovascular disease is limited. Key elements include auscultation for pathologic murmurs suggestive of HCM or valvular disease, measurement of blood pressure, and assessment for phenotypic features of Marfan syndrome or other connective tissue disorders (9,16). While rarely diagnostic on its own, abnormal findings can guide appropriate use of advanced investigations.

Table 3. Etiologies and key clinical risk markers for sudden cardiac death in children and adolescent athletes

Etiology	Key clinical clues/risk markers
Hypertrophic cardiomyopathy	Family history of SCD, exertional syncope, harsh systolic murmur, abnormal ECG (deep Q waves, repolarization changes)
Arrhythmogenic right ventricular cardiomyopathy	Ventricular arrhythmias, T-wave inversion in V1-V3, unexplained palpitations during exercise
Congenital coronary anomalies	Exertional chest pain or syncope without murmur, ischemic ECG changes during exertion
Long QT syndrome	Prolonged QT interval on ECG, exertional syncope, unexplained seizures, family history of SCD
Catecholaminergic polymorphic VT	Exercise-induced syncope, bidirectional VT on exercise testing, family history of sudden death
Brugada syndrome	Coved-type ST elevation in V1-V3, nocturnal agonal respiration, family history of SCD
Myocarditis	Recent viral illness, chest pain, arrhythmias, elevated troponin
Premature coronary artery disease	Traditional risk factors: obesity, smoking, hypertension, dyslipidemia
Kawasaki disease sequelae	History of Kawasaki disease, coronary aneurysms, ischemia or arrhythmia during exertion
Extrinsic factors	Stimulant/performance-enhancing drug use, dehydration, electrolyte imbalance, extreme endurance training

SCD: Sudden cardiac death, VT: Ventricular tachycardia, ECG: Electrocardiography

Table 4. The 12-element AHA preparticipation cardiovascular screening recommendations (2007 Statement) (3)

Domain	Elements
Personal history	1. Exertional chest pain/discomfort 2. Unexplained syncope/near-syncope 3. Excessive exertional dyspnea/fatigue or palpitations 4. Prior recognition of a heart murmur 5. Elevated systemic blood pressure
Family history	6. Premature death (sudden/unexpected) before 50 years of age due to heart disease 7. Disability from heart disease in a close relative <50 years 8. Knowledge of inherited cardiac conditions (HCM, LQTS, Marfan syndrome, etc.)
Physical examination	9. Heart murmur 10. Abnormal femoral pulses 11. Physical stigmata of Marfan syndrome 12. Brachial artery blood pressure (sitting position)

HCM: Hypertrophic cardiomyopathy, LQTS: Long QT syndrome, AHA: American Heart Association

Red Flags in Pediatric Athletes

Certain clinical features should raise immediate concern for an increased risk of SCD, including exertional syncope, chest pain or palpitations during activity, unexplained seizures, documented arrhythmias, and a family history of sudden death before age 50 (3,10,13). Exertional syncope, chest pain and a positive family history are regarded as particularly high-risk warning signs. Although the positive predictive value of individual symptoms is low in the general population of athletes, their presence is associated with a substantially increased relative risk and should always prompt further cardiovascular assessment.

Special Tests

When history or physical examination raises suspicion, special tests are indicated.

• **Electrocardiography:** The ESC and international consensus guidelines advocate routine ECG, whereas the AHA/ACC recommend its use only in selected cases. Modern athlete-specific interpretation standards, such as the Seattle Criteria and International Criteria, have reduced false-positive rates while maintaining sensitivity (4,6). Echocardiography is valuable for structural evaluation when a murmur or abnormal ECG is detected but is not recommended for universal screening because of cost and limited availability (2,10,19).

• **Exercise Testing (Treadmill/Exercise ECG):** Exercise testing may unmask arrhythmias not evident at rest, particularly in conditions such as CPVT and LQTS. It may also help evaluate exertional chest pain, ischemic ECG changes, and functional capacity in athletes with suspected coronary anomalies or repaired CHD. However, its role in routine population-based screening is limited, and it is best applied in athletes with concerning symptoms or abnormal baseline findings (20,21).

• **Advanced Imaging (Cardiac Magnetic Resonance, Computed Tomography):** Used in selected athletes to clarify suspected cardiomyopathy, anomalous coronary arteries, or myocarditis (22,23). Genetic testing is considered in athletes with a strong family history or features suggestive of inherited arrhythmia syndromes; its role in routine screening remains limited, but may expand with decreasing costs (24).

Challenges and Controversies

Despite its potential benefits, preparticipation cardiac screening in young athletes remains an area of significant debate.

False Positives and False Negatives

The use of ECG as a universal screening tool has improved sensitivity for detecting silent cardiovascular disease, but is associated with considerable rates of false-positive findings, particularly when interpreted without athlete-specific criteria; false negatives also remain a concern for certain conditions. Early ECG screening programs using non-athlete-specific criteria reported false-positive rates as high as 10–20% in some cohorts, largely due to misinterpretation of physiological adaptations of the athlete's heart. With the adoption of contemporary athlete-specific interpretation standards, such as the Seattle and subsequent International criteria, false-positive rates have fallen to approximately 3–5% while maintaining high sensitivity for clinically relevant cardiomyopathies and channelopathies. Nevertheless, false-negative results still occur, particularly in conditions that may have a normal or only subtly abnormal ECG, such as anomalous coronary arteries or very early-stage cardiomyopathies; this remains an inherent limitation of any screening strategy (6,9,16,25,26).

Cost-Effectiveness and Feasibility

Another major controversy is the economic and logistical feasibility of implementing mass screening programs. Studies from the US have raised concerns about the high cost of routine ECG screening relative to its yield, particularly in large populations (17). In contrast, European experiences suggest potential long-term benefits when false positives are reduced using refined interpretation criteria. Nevertheless, disparities in healthcare resources across regions make universal recommendations difficult to establish (13).

Ethical and Legal Issues

Ethical dilemmas arise when athletes are disqualified from sports based on screening results, especially in conditions with variable penetrance or uncertain clinical significance. Disqualification may protect the athlete, but it can also cause psychosocial harm and raise legal challenges. Families and clinicians often face a delicate balance between ensuring athlete safety and preserving the athlete's autonomy to participate. Ethical reflections on medical disqualification emphasize that disqualification can carry substantial psychosocial, financial, and identity-related consequences for the athlete and their family (27). Moreover, issues of equity arise, as resource-limited settings may lack the infrastructure for advanced screening, potentially widening disparities in care.

In Türkiye, sports participation and athlete licensing are regulated by national youth and sports legislation and ministerial regulations, which require a medical report documenting fitness to participate when applying for a license. In routine clinical practice, preparticipation evaluations are frequently performed by family physicians, sports medicine

specialists, and cardiologists; the issuance of an athlete license implies medicolegal responsibility for the certifying clinician. These national regulations frame the ethical and legal context in which preparticipation cardiac screening is implemented (28).

Future Perspectives

Future directions in preparticipation cardiac screening focus on integrating novel technologies with traditional approaches. Artificial intelligence-assisted ECG interpretation may reduce false positives and improve accuracy (29). Genetic testing, although currently limited to selected cases, is expected to expand as costs decrease and interpretation frameworks improve (24). Advanced imaging, particularly echocardiography and cardiac magnetic resonance imaging, may play an increasing role in selected high-risk athletes (19,22,23). The future of screening is likely to move toward personalized risk assessment, integrating multimodal data to optimize both sensitivity and feasibility.

Conclusion

In conclusion, SCD in young athletes, though rare, has profound clinical and societal consequences. Preparticipation screening offers an opportunity to identify individuals at risk, but its implementation remains controversial due to variability in guidelines, diagnostic yield, and cost-effectiveness. While the AHA/ACC emphasizes a focused history and physical examination, the ESC and international consensus groups advocate for routine ECG, reflecting different interpretations of available evidence. Key challenges include false positives, limited resources, and ethical dilemmas related to sports disqualification. Nevertheless, ongoing advances in ECG interpretation, imaging, and genetics are expected to refine risk stratification. Future approaches will likely emphasize personalized cardiovascular assessment, balancing athlete safety with the right to participate in sports. A proposed stepwise algorithm, as shown in Figure 1, summarizes how structured history and examination, targeted ECG use, and selective application of further tests can be integrated into

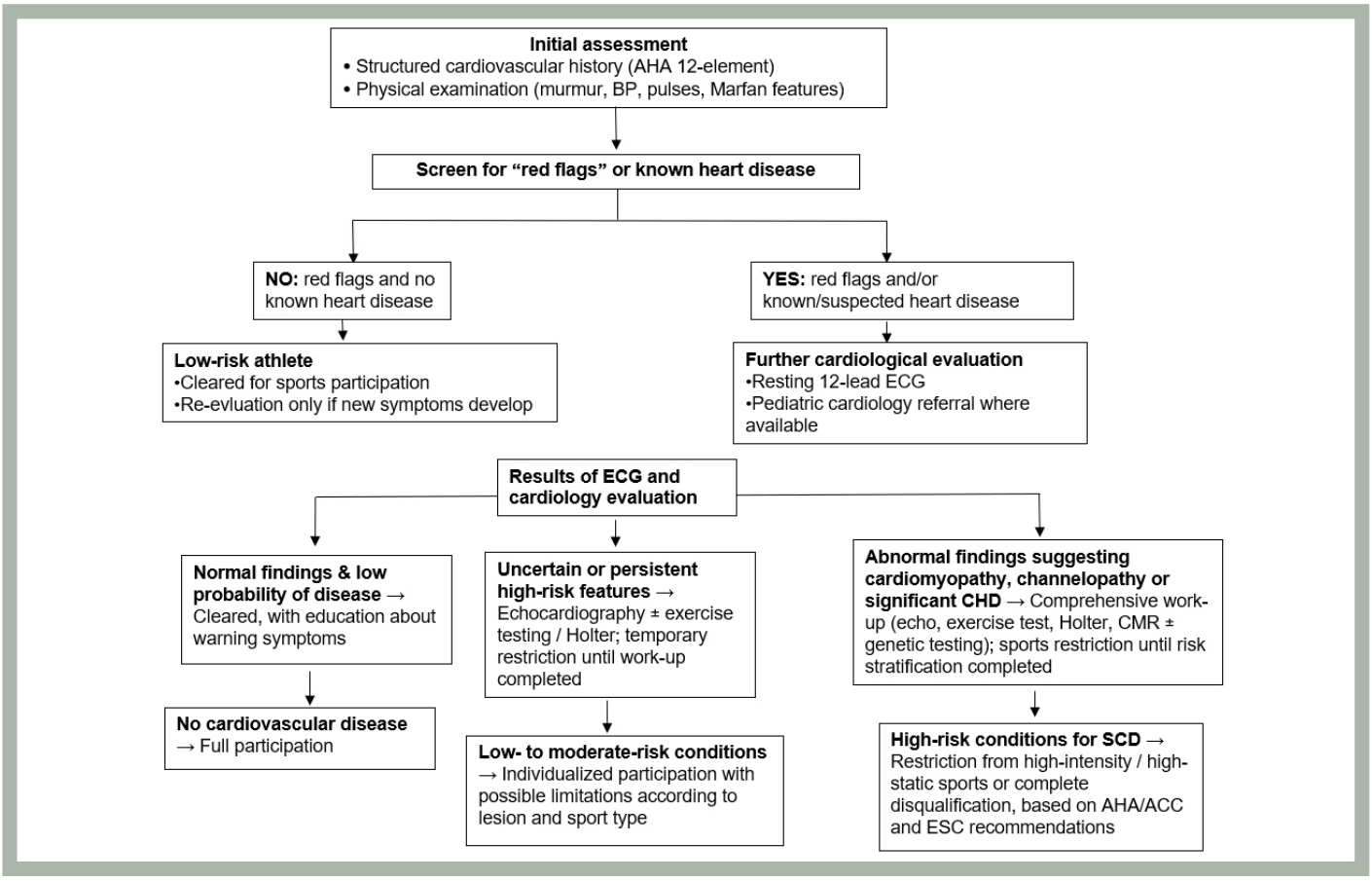

Figure 1. Proposed algorithm for preparticipation cardiac evaluation in children and adolescents

BP: Blood pressure, ECG: Electrocardiography, CHD: Congenital heart disease, CMR: Cardiac magnetic resonance, SCD: Sudden cardiac death, AHA/ACC: American Heart Association/American College of Cardiology, ESC: European Society of Cardiology

a practical preparticipation evaluation pathway. In Türkiye, as in many countries with diverse healthcare resources, adopting a feasible and cost-effective strategy that combines careful clinical evaluation with selective use of ECG and imaging may represent the most practical approach. Efforts to increase awareness among physicians, families, and sports organizations will be critical in implementing effective and equitable screening programs.

Footnotes

Authorship Contributions

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