Is There Evidence for Recommending Electrocardiogram as Part of the Pre-Participation Examination?

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Abstract: Sudden cardiac death (SCD) is the leading cause of death in young athletes on the playing field and typically the result of undiagnosed structural or electrical cardiovascular disease. Cardiovascular screening in athletes is routinely practiced and endorsed by most major sporting and medical associations, but universal agreement on a single screening strategy to identify athletes at risk for SCD remains a topic of tremendous debate. The pool of scientific evidence supporting the efficacy and cost-effectiveness of electrocardiogram (ECG) screening for athletes is growing. However, feasibility and practical concerns regarding false-positive results, cost-effectiveness, physician infrastructure, and health care resources for large-scale implementation of ECG screening still exist. This article examines the evidence related to ECG screening in athletes and presents a contemporary model for primary prevention of SCD in sport.

Key Words: sudden cardiac death, athlete, sport, screening, prevention, electrocardiogram

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INTRODUCTION

Exercise and sport are widely encouraged to prevent illness and promote health. However, exercise and physical conditioning also trigger sudden cardiac arrest (SCA) in individuals with underlying cardiovascular disease. This "exercise paradox" is too often highlighted by the sudden death of a young athlete during training or competition. Sudden cardiac death (SCD) is the leading cause of mortality in young athletes on the playing field and typically the result of undiagnosed structural or electrical cardiovascular disease.[1–3] Over the past 2 decades, high-profile deaths of professional and elite athletes have brought this issue to the forefront of the international sports medicine and cardiology communities. Although the precise frequency of SCD in athletes remains disputed, the catastrophic death of a young athlete predictably raises intense public and medical scrutiny regarding pre-athletic screening and existing strategies for prevention.

Cardiovascular screening in athletes is routinely practiced and endorsed by most major sporting and medical associations, including the American Heart Association (AHA), the European Society of Cardiology (ESC), and the International Olympic Committee (IOC).[4–6] However, universal agreement on a single screening strategy to identify athletes at risk for SCD remains elusive and a topic of tremendous debate. The screening controversy is centered on the inclusion (or not) of a resting 12-lead electrocardiogram (ECG) in addition to a history and physical examination during the pre-participation evaluation. Important data exist from the Italian screening program that a protocol using ECG reduces the incidence of SCD in athletes.[7] However, application of ECG screening in other countries with different or more heterogeneous populations has raised concerns regarding false-positive results, cost-effectiveness, physician infrastructure, and health care resources.[8] This article examines the evidence related to ECG screening in athletes and presents a contemporary model for primary prevention of SCD in sport.

INCIDENCE OF SUDDEN CARDIAC DEATH

Sudden cardiac death is the leading cause of death in young athletes during exercise.[1,3] However, the exact frequency of SCD in athletes is unknown, and it is difficult to compare incidence studies with highly variable methodology and from widely different geographic regions (Table 1). Reports in the United States have relied heavily on case identification through search of public media reports, catastrophic insurance claims, and other electronic databases, with estimates ranging from 1:160 000 to 1:300 000 deaths per year in young competitive athletes (age, 12-35 years).[1,9,10] These studies may underestimate the incidence of SCD due to the lack of a mandatory reporting system and potential for incomplete identification of all cases.

Accurate calculation of the incidence of SCD in athletes requires a reliable reporting system with precise reflection of the number of cases per year (numerator) and a universal definition of "athlete" with an exact count of athlete participants per year (denominator). Recently, a 5-year review was conducted on the etiology and incidence of sudden death in the National Collegiate Athletic Association (NCAA) athletes from 2004-2008.[3] Cases were identified primarily through the NCAA Resolutions Database, a recommended reporting system for institutions to the NCAA Director of Health and Safety on the death of any NCAA athlete. Forty-four cardiovascular-related sudden deaths were identified during this period with an average of 400 000 individual athlete participants per year. Cardiovascular-related sudden

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TABLE 1. Incidence of Sudden Cardiac Death in Children and Young Athletes

Study	Population	Methods and Reporting System	Incidence
Van Camp et al[9]	High school and college athletes aged 13 to 24 years (United States)	Public media reports and other reported cases	1:300 000
Maron et al[10]	High school athletes in Minnesota aged 13-19 years (United States)	Catastrophic insurance claims	1:200 000
Eckart et al[11]	Military recruits aged 18 to 35 years (United States)	Mandatory, autopsy-based	1:9000
Drezner et al[12]	College athletes aged 18 to 23 years (United States)	Retrospective survey	1:67 000
Corrado et al[7]	Competitive athletes aged 12 to 35 years (Italy)	Mandatory registry for SCD	1:25 000
Maron et al[1]	Competitive athletes aged 12 to 35 years (United States)	Public media reports and other electronic databases	1:166 000
Drezner et al[13]	High school athletes aged 14 to 17 years (United States)	Cross-sectional survey	1:23 000
Atkins et al[14]	Adolescents and young adults aged 12 to 24 years (United States and Canada)	Prospective, population-based, EMS reports	1:27 000
Chugh et al[15]	Children in Oregon aged 10 to 14 years (United States)	Prospective, population-based, EMS/hospital reports	1:58 000
Asif et al[3]	College athletes aged 17 to 23 years (United States)	NCAA resolutions database, public media reports, and catastrophic insurance claims	1:45 000

EMS, emergency medical services; NCAA, National Collegiate Athletic Association; SCD, sudden cardiac death.

death represented 72% of fatalities during exertion, with an SCD incidence of 1:45 000 NCAA athletes per year.[3]

Other studies have also reported a higher incidence of SCD than initial estimates in the United States.[7,11–15] The Veneto region of Italy uses a regional registry for juvenile sudden death and reported an SCD incidence of 1:28 000 for young competitive athletes (age, 12-35 years) before implementing a national screening program.[7] In US military recruits (age, 18-35 years), the incidence of nontraumatic exercise-related SCA was 1:9000.[11] A prospective population-based study conducted at 11 US and Canadian cities and using rigorous methodology with all cases of SCA collected through the emergency medical services system reported an incidence of SCA from cardiovascular disease of 1:27 000 in children and young adults (age, 14-24 years).[14] Another US population-based study found the incidence of SCA in children (age, 10-14 years) to be 1:58 000.[15]

These studies raise the question as to whether SCA/SCD is more common in competitive athletes versus an age-matched general population and if this risk justifies a separate cardiovascular screening program for competitive athletes. It is generally accepted that exercise and intense physical exertion through athletic participation increase the likelihood of sudden death for many disorders predisposing to SCA. Corrado et al[16] identified a 2.5 times relative risk for SCD due to sports activity in athletes versus an age-matched nonathletic population. Exercise is considered the exposure (risk factor) for SCA in individuals with an underlying cardiovascular disorder, and athletes may be at elevated risk of SCD compared with nonathletes due to the frequency of their exercise, perhaps justifying a more intensive screening program.

On the other hand, all children are not competitive athletes, but most children are active and exercise in some way. According to statistics from the Centers for Disease Control, cardiovascular disease is only second to malignancy, as the leading medical cause of death in individuals younger than 24 years, accounting for more than 2400 fatalities per year in the United States.[17] Thus, if specific screening tests or procedures are valuable for the minority of children and young adults who participate in organized sports, should these tests also be available for all children?[18]

Indeed, there are important ethical and public health grounds to develop an effective cardiovascular screening program for all children. However, current standards, existing medical recommendations, and administrative and medicolegal requirements in the United States and most other countries demand that medical clearance for competitive athletes be provided through a pre-participation evaluation before participation in organized sports. The challenge and responsibility of the medical community is to perform a screen that is effective.

PURPOSE OF CARDIOVASCULAR SCREENING

What is the purpose of pre-participation cardiovascular screening? Is it purely to prevent SCD, or is the goal of screening to identify young athletes with cardiovascular conditions at risk for SCD? The AHA states that the principal objective of screening is to reduce the cardiovascular risks associated with physical activity and enhance the safety of athletic participation.[4] The American College of Cardiology contends that the "ultimate objective of pre-participation screening of athletes is the detection of 'silent' cardiovascular abnormalities that can lead to SCD."[19] And, the Preparticipation Physical Evaluation monograph states that the primary objective of screening is to detect potentially life-threatening or disabling conditions before undergoing specific athletic participation.[20]

Thus, perhaps it is the prevalence of cardiovascular conditions with the potential for sudden death, rather than the incidence of SCD itself, that should influence the rigor of our screening procedures. The goal of screening is to detect occult cardiovascular disorders, because many of these conditions can be effectively managed through activity modification and medical intervention (pharmacotherapy, radiofrequency ablation, implantable cardioverter defibrillator, or even surgery) to reduce the risk of sudden death. The AHA estimates the combined disease prevalence of all cardiovascular disorders that potentially predispose young

TABLE 2. Prevalence of Cardiovascular Disorders at Risk for Sudden Cardiac Death

Study	Population	Prevalence, %
Maron et al[4] (2007)	Estimate in competitive athletes aged 12 to 35 years (United States)	0.3
Fuller et al[21]	5617 high school athletes (United States)	0.4
Corrado et al[7]	42 386 athletes aged 12 to 35 years (Italy)	0.2
Wilson et al[22]	2720 athletes and children aged 10 to 17 years (United Kingdom)	0.3
Bessem et al[23]	428 athletes aged 12 to 35 years (the Netherlands)	0.7
Hevia et al[24]	1220 amateur athletes (Spain)	0.16
Baggish[25]	510 college athletes (United States)	0.6

athletes to SCD to be 0.3%.[4] In contrast to the wide range of estimates for SCD incidence, the prevalence of potentially lethal cardiovascular diseases in athletes has consistently ranged between 0.2% and 0.7% in studies using noninvasive cardiovascular testing (Table 2).[7,21–25] In other words, approximately 1 in 500 athletes or more may harbor an occult cardiovascular condition that places them at risk for SCD.

HISTORY AND PHYSICAL EXAMINATION

In 1996, the AHA first provided consensus guidelines on pre-participation cardiovascular screening in athletes with specific recommendations for a detailed personal and family history and physical examination.[26] More than a decade later, little is known about the sensitivity and specificity of such a protocol, and no study to date using history and physical alone has demonstrated any significant detection of underlying cardiovascular disease in athletes. A substantial challenge to screening is that most apparently, healthy athletes with unsuspected cardiovascular disease are asymptomatic. Sudden death is the first clinical manifestation of cardiac disease in up to 60% to 80% of athletes with SCD.[27–29] The lack of sensitivity of a screening model based only on history and physical examination is demonstrated in a report of 115 cases of SCD in young athletes in whom screening lead to the correct diagnosis in only 1 athlete (0.9%).[28]

Successful detection of athletes with symptoms of cardiovascular disease requires that physicians ask the appropriate questions (Appendix). Warning symptoms and/or a significant family history may be present in an important but limited proportion of athletes at risk for SCD. Unfortunately, standardized questionnaire forms developed to assist health care providers in performing a comprehensive pre-participation evaluation have been grossly underused in the primary care and scholastic communities.[30,31] Although there remains general agreement that conducting a comprehensive personal and family history and physical examination is important, the sensitivity of a history and physical examination alone for cardiovascular screening of athletes is limited.

ELECTROCARDIOGRAM SCREENING

The value of adding noninvasive cardiovascular tests, such as ECG, to the screening process of athletes is widely debated.[32,33] In 2007, the AHA reaffirmed their recommendations against universal ECG screening in athletes, citing a low prevalence of disease, poor sensitivity, high false-positive rate, poor cost-effectiveness, and a lack of clinicians to interpret the results.[4] In contrast, the ESC,[5] IOC[6,34] and the governing associations of several US and international professional sports leagues endorse the use of ECG in the pre-participation screening of athletes. These recommendations are supported by studies showing that ECG is more sensitive than history and physical examination alone in identifying athletes with underlying cardiovascular disease (Table 3).

Inherited cardiomyopathies are the most common cause of SCD in young athletes, with hypertrophic cardiomyopathy (HCM) accounting for more than one-third of cases in the United States and arrhythmogenic right ventricular cardiomyopathy predominating in Italy.[1,7] Approximately 95% of individuals with HCM and 80% of individuals with arrhythmogenic right ventricular cardiomyopathy exhibit ECG abnormalities that can be detected on ECG screening.[36–38] Corrado et al[39] found that ECG had a 77% greater power than history and physical examination to detect HCM, and disqualification from sport in athletes detected with HCM reduced mortality compared with death rates in nonathletes with HCM. Electrocardiogram also has a high negative predictive value (99.98%), essentially excluding HCM in athletes with a normal ECG.[40]

In 2006, Corrado et al[7] reported data from a national pre-participation screening program in Italy in 42 386 athletes for more than 25 years. The Italian model consists of an integrated screening protocol using a standardized

TABLE 3. Positive Screens Requiring Further Testing by History and Physical Examination (H&P) Versus Electrocardiogram (ECG)

		Positive Results Requiring Further Testing			Sensitivity to Detect Potentially Lethal Cardiovascular Disease		
Study	Population	H&P, %	ECG, %	Total, %	No. of Cases	H&P, %	ECG, %
Fuller et al[21]	5617 high school athletes (United States)	7.8	4.8	10	22	27	73
Corrado et al[7]	42 386 athletes aged 12 to 35 years (Italy)	—	—	9	—	—	—
Nora et al[35]	9125 high school students (United States)	—	2	2	—	—	—
Wilson et al[22]	2720 athletes and children aged 10 to 17 years (United Kingdom)	2.5	1.5	4	9	0	100
Bessem et al[23]	428 athletes aged 12 to 35 years (the Netherlands)	8	8	13	3	33	67
Hevia et al[24]	1220 amateur athletes (Spain)	1.2	6.1	7.4	2	0	100
Baggish et al[25]	510 college athletes (United States)	6	16	20	3	33	67

history, physical examination, and ECG. Disqualification and subsequent medical care of athletes with cardiovascular disorders produced a 10-fold reduction in the incidence of SCD in young competitive athletes and an 89% reduction of SCD as a result of cardiomyopathy.[7] This is the only study to date with long-term outcome-based data on survival after screening and disqualification of athletes at an increased risk of SCD. Although only 0.2% of athletes were disqualified for potentially lethal cardiovascular conditions, the study reported a 7% false-positive rate and a 2% overall disqualification rate, raising concerns that adopting such a program in the United States would lead to an unacceptable number of disqualifications in athletes with a low risk for SCD.[8]

Concern for a high number of false-positive results leading to unnecessary diagnostic testing and restriction from athletic participation is the primary objection to adopting ECG screening in the United States. An initial screening study performed in the United States over 2 decades ago reported a false-positive rate of 15%.[41] However, more recent studies applying modern strict ECG criteria to screen athletes have resulted in substantially lower false-positive rates. Pelliccia et al[42] reported on 32 652 ECGs in young amateur athletes (median age 17; range, 8-78 years) and distinct ECG abnormalities, suggesting that cardiac disease was found in only 4.8% of athletes. In a study of 2720 competitive athletes and physically active school children in the United Kingdom, Wilson et al[22] reported a false-positive rate of 3.7% using history, physical examination, and ECG, with only 1.9% of false-positives determined by ECG alone. In this study, 9 athletes (0.3% of those screened) were found to have a cardiovascular condition known to cause SCD in the young, and all of these athletes were detected by ECG and not by history or physical examination.[22] Nora et al[35] reported preliminary findings of ECG screening in 9125 young adults (age, 14-18 years) from the midwest region of the United States and found only 2% of ECGs to be abnormal using modern ECG criteria. In a recent report, Hevia et al[24] investigated the Italian screening model in 1220 amateur athletes from Spain and found that 6.1% of athletes had a positive ECG, and 2 (approximately 1 in 600) were diagnosed with HCM identified only by ECG. None of the 15 cases (1.2%) with a positive criterion on history or physical examination had structural cardiac disease on echocardiogram.[24]

Electrocardiogram does not detect all disorders predisposing to SCD. Electrocardiogram is unable to identify premature coronary artery disease and congenital coronary anomalies, which account for approximately 20% of SCD in young athletes. In addition, ECG screening may not detect about 5% of patients with HCM; however, patients with HCM and a normal ECG seem to exhibit a less severe phenotype and lower cardiac-related mortality compared with patients with HCM with abnormal ECGs.[43]

ELECTROCARDIOGRAM INTERPRETATION

It is critical to recognize that the total-positive and false-positive rates for any ECG screening study is immensely affected by the criteria chosen to define "abnormal." There is an urgent need for uniform terminology when describing ECG findings in athletes.[44] Many ECG changes once referred to as "abnormal" are now recognized as physiologic and part of benign cardiac adaptation in athletes (so-called athlete's heart). Physicians interpreting ECGs in athletes should be familiar with common training-related ECG alterations that are normal variants. In contrast, training-unrelated ECG changes suggest the possibility of underlying pathology, require further workup, and should be considered abnormal. Recently, the ESC Section on Sports Cardiology published an international position statement summarizing modern recommendations to distinguish pathologic ECG abnormalities from physiologic ECG alterations in athletes.[45] A summary of these recommendations is provided in Table 4.

The most significant change from past ECG guidelines is the elimination of isolated QRS voltage criteria for left ventricular hypertrophy (LVH) as a cause for further evaluation. Isolated voltage criteria for LVH is an insensitive marker for LVH, found in up to 40% of highly trained athletes and in less than 2% of patients with HCM.[46] Sathanandam et al[47] found that ECG voltage criteria for LVH was not associated with a diagnosis of HCM in 8395 young adults undergoing pre-participation screening ECGs. Isolated increases in QRS amplitude are common in trained athletes and do not require investigation with echocardiography. However, nonvoltage criteria for LVH such as atrial enlargement, left axis deviation, a "strain" pattern of repolarization, ST-segment depression, T-wave inversion, or pathologic Q waves are abnormal and require further evaluation.[45]

A recent study by Baggish et al[25] screened 510 college athletes with history, physical examination, ECG, and echocardiography. Three athletes were identified with a potentially lethal cardiovascular disease: 2 athletes detected by ECG (HCM and myocarditis) and 1 athlete detected by physical examination

TABLE 4. Recommendations for Electrocardiogram (ECG) Interpretation in Athletes

Normal[a]	Abnormal[b]
Sinus bradycardia	T-wave inversion
First-degree AV block	ST-segment depression
Incomplete RBBB	Pathological Q waves
Early repolarization	Left atrial enlargement
Isolated QRS voltage criteria for LVH	Left-axis deviation/left anterior hemiblock
	Right axis deviation/left posterior hemiblock
	Right ventricular hypertrophy
	Ventricular pre-excitation
	Complete LBBB or RBBB
	Long or short QT interval
	Brugada-like early repolarization

[a]Training-related ECG alterations are common, physiologic adaptations to regular exercise and are considered normal variants in athletes.

[b]Any abnormal finding is considered training-unrelated and suggests the possibility of underlying pathologic cardiac disease, requiring further diagnostic work-up.

Based on the 2010 European Society of Cardiology position statement on ECG interpretation in athletes.[45]

AV, atrioventricular; LBBB, left bundle branch block; LVH, left ventricular hypertrophy; RBBB, right bundle branch block.

(moderate pulmonic stenosis). All 3 athletes were asymptomatic, and inclusion of the ECG improved sensitivity for detecting important cardiac abnormalities from 45.5% to 90.9%. The study reported a false-positive ECG rate of 16%.[25] However, 54% of the ECG abnormalities listed were isolated voltage criteria for LVH, a criterion no longer considered abnormal.

COST-EFFECTIVENESS

Cost-effectiveness estimates on mass ECG screening in athletes is highly variable. The differences result from disparities in methodology, variation in baseline statistics used for SCD incidence and false-positive rates, and differences in the assigned cost for ECG and additional cardiovascular evaluations. Fuller et al[48] estimated a cost per life-year saved of $44 000 if ECG screening was used in high school athletes. In contrast, the AHA estimated a cost of $330 000 for each athlete detected with cardiac disease and $3.4 million for each death prevented.[4] The AHA calculations are based on an SCD incidence of 1 in 200 000 and a false-positive rate of 15%.[4,10,41] Another report estimated a cost per life-year saved as low as $28 000 if the AHA calculation was based on an incidence of 1:50 000 deaths per year and a false-positive ECG rate of 5%.[49]

Pre-participation screening as practiced in the United States already is undertaken at considerable cost. Wheeler et al[50] recently assessed the costs and survival rates in US athletes who were screened with or without ECG. The study estimated that ECG resulted in 2.1 life-years saved per 1000 athletes screened, with an incremental cost-effectiveness ratio of $42 000 per life-year saved for ECG screening compared with a cardiovascular-focused history and physical examination alone.[50]

CONCLUSIONS

Sudden cardiac death is the leading fatality in sport, with compelling justification to provide pre-participation screening (Table 5). A comprehensive personal and family history and physical examination are recommended components of cardiovascular screening in athletes but offer little sensitivity in identifying athletes at risk for SCD, and the value of these measures alone is questionable. Integrated programs using ECG offer the only model shown to reliably identify athletes at the risk for SCD and the only evidence that such a program can reduce the rate of SCD in athletes. Electrocardiogram should be recommended and offered to athletes as part of a pre-participation cardiovascular screen. Concern about excessively high abnormal results does not reflect more contemporary standards of ECG interpretation. Electrocardiogram screening must be conducted using modern criteria to distinguish physiologic cardiac adaptations from underlying pathology and limit unnecessary diagnostic evaluations.

Feasibility and practical concerns still exist regarding large-scale implementation of ECG screening in the United States and many countries. Further research is needed to better define the true prevalence of cardiovascular disease in various populations, the cost of screening and of investigating positive screens through subsequent testing, and the potential reduction of SCD through withdrawal from athletic participation and appropriate medical intervention. However, the pool of scientific evidence supporting the efficacy and cost-effectiveness of ECG screening for athletes is growing. To confront the remaining challenges in the prevention of SCD in sport, we must move beyond a debate disputing incidence and false-positive rates derived from studies with vastly different methodology and move toward advancements in physician education and improvements to our health system infrastructure.

TABLE 5. Recommendations for Contemporary Cardiovascular Screening in Young Athletes

1. Comprehensive pre-participation evaluation using a detailed personal and family history questionnaire, along with a properly conducted physical examination, beginning at age 12 and repeated every 2 years.
2. A questionnaire should be administered in interval years to assess the development of any new cardiovascular symptoms. Blood pressure also should be evaluated at that time.
3. Electrocardiogram screening should be offered (at minimum) on athlete matriculation to high school, college, and professional athletics.
4. Electrocardiogram screening should be interpreted with modern criteria to distinguish physiologic cardiac adaptations from underlying pathology.

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APPENDIX. Recommended Cardiovascular Screening Questions

	Yes	No
1. Have you ever passed out or nearly passed out during or after exercise?		
2. Have you ever had discomfort, pain, tightness, or pressure in your chest during exercise?		
3. Does your heart ever race or skip beats (irregular beats) during exercise?		
4. Has a doctor ever told you that you have any heart problems? If so, check all that apply: ☐ High blood pressure ☐ A heart murmur ☐ High cholesterol ☐ A heart infection ☐ Kawasaki disease ☐ Other: ________		
5. Do you get lightheaded or feel more short of breath than expected during exercise?		
6. Have you ever had an unexplained seizure?		
7. Do you get more tired or short of breath more quickly than your teammates during exercise?		
8. Has any family member or relative died of heart problems or had any unexpected or unexplained sudden death before age 50 (including drowning, unexplained car accident, or sudden infant death syndrome)?		
9. Does anyone in your family have a heart problem, pacemaker, or implanted defibrillator?		
10. Has anyone in your family had unexplained fainting, unexplained seizures, or near drowning?		
11. Does anyone in your family have: hypertrophic cardiomyopathy, Marfan syndrome, arrhythmogenic right ventricular cardiomyopathy, long QT syndrome, short QT syndrome, Brugada syndrome, or catecholaminergic polymorphic ventricular tachycardia?		

Based on the Preparticipation Physical Evaluation, 4th edition.[20]