



# A discussion of electrocardiographic screening and sudden cardiac death prevention: evidence and consensus

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## Purpose of review

Frequent media reports of sudden cardiac arrest or death (SCA/SCD) keep alive a debate as to how best to prevent these tragedies. Several new studies in the past 2 years serve as an impetus to reframe the debate into a reasonable discussion that seeks to obtain more evidence wherever needed and to develop a consensus wherever possible.

## Recent findings

Since the report from Italy of the 89% decrease in SCD over 25 years of an ECG-based cardiovascular screening program, proponents and opponents of ECG screening have been busily debating. Multiple studies on screening have shown that adding an ECG to a history and physical examination is more sensitive than history and physical examination alone in identifying those potentially at risk. A major gap exists regarding managing these new 'patients' as their clinical course is not known. Reports, without data, have warned of unintended or harmful consequences of ECG screening. Economic models have shown cost-effectiveness of ECG screening to be variable.

## Summary

Studies suggest that adding an ECG to the screening is a very reasonable effort that will identify at-risk youth and prevent SCD, but more information is needed. If data support the addition of an ECG, efforts should be made to make this opportunity available.

## Keywords

athletes, children, electrocardiogram, history and physical examination, preparticipation screening, sudden cardiac death

## INTRODUCTION

Sudden cardiac arrest (SCA) or sudden cardiac death (SCD) in the young often occurs without warning or recognition of warning symptoms. It is estimated that SCA claims the lives of over 1000 children and adolescents each year in the United States, accounting annually for approximately 5% of all childhood deaths in children aged 5–19 years, with a reported incidence of 0.6–8/100 000, as shown in Table 1 [1–8,9<sup>\*\*\*</sup>,10,11<sup>\*\*</sup>,12<sup>\*</sup>–14<sup>\*</sup>,15,16<sup>\*</sup>,17,19,20]. The lack of a registry or reporting system in the United States results in estimates often derived from media reports that have been shown to capture only half of the actual events [11<sup>\*\*</sup>]. The relative infrequency of these events does not diminish their impact upon families and communities, or diminish the importance or relevance of this issue to the public health.

SCD is the major cause of death in young athletes on the field. In children, SCA is associated

with structural and electrical cardiac abnormalities including hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, long QT syndrome, other electrophysiologic conditions including Brugada syndrome, Wolff–Parkinson–White syndrome, catecholaminergic polymorphic ventricular tachycardia, coronary artery anomalies,

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## KEY POINTS

- The sensitivity of adding an ECG to the history and physical examination is clearly better than screening without an ECG.
- Improvements in ECG test characteristics by determining standards in youth according to age, sex, race and ethnicity will decrease false positives.
- The infrastructure for cardiovascular screening in youth already exists with the preparticipation evaluation, so the addition of an ECG at selected intervals (e.g., 7th and 10th grade) would be feasible.
- Screening one or two times during the 10–19-year age range when risks for SCA are highest can be cost-effective in the United States.
- Ongoing research should be performed on any systematic screening in this country to fill the knowledge gaps that include incidence of SCD and changes associated with screening, prevalence of SCD conditions, timing and frequency of screening, targeted or nontargeted screening, outcomes of those excluded from sport or accommodations to allow sport to continue, and natural history of conditions identified by screening in asymptomatic individuals.

congenital heart defects, myocarditis, Marfan syndrome, and others [20,21]. Conditions that can be identified using the ECG are responsible for at least two-thirds of SCA in the young, with coronary artery anomalies being the most notable exception [22].

SCA in athletes is a catastrophic event with a low survival rate (4–21%) that demands reevaluation of our current screening and prevention practices [23].

## THE SCREENING DISCUSSION/DEBATE

There is a consensus of most organizations involved in sport that cardiac screening should be performed, given the increase in risk of sudden death by 2.5-fold during activity in vulnerable individuals [24–27]. In fact, the American Heart Association (AHA) and European Society of Cardiology (ESC) agree on the principle of cardiac screening and even that a history and physical examination (H&P) should be included, but the interpretation of the evidence on screening, and the lack thereof, results in a divide in the recommendation regarding adding an ECG to the evaluation. Under AHA guidelines, the United States continues to recommend screening only by H&P without an ECG [19]. This issue has been the topic of many articles and debates regarding the best method to use for cardiac screening [28–32,33<sup>11</sup>,34<sup>11</sup>].

Observational data from Italy, using a mandatory ECG screening program, demonstrate that ECG screening can identify children and adolescents with undiagnosed conditions predisposing to SCA and decrease SCD [35,36]. There is concern as to whether these data are applicable to the United States or other populations. There is a general consensus that ECG is more sensitive in identifying those at risk for SCA than H&P alone [37]. ECG, either alone or with H&P, has been shown to be more cost-effective than H&P alone, or other forms of screening such as echocardiography. There is recognition that the ECG has a false-positive rate that leads to additional testing, possible disqualification, and the potential for anxiety or distress until the correct diagnosis is determined [38<sup>11</sup>]. However, the same issue exists with the H&P with a much lower sensitivity. At the present time, the best method to identify those children at risk for SCA through primary screening is controversial [39,40]. Recent articles and new studies indicate that it is time to readdress these issues [9<sup>11</sup>,18,22,33<sup>11</sup>,34<sup>11</sup>,41–43].

Demonstrating the importance of this issue, the National Heart Lung and Blood Institute (NHLBI) convened a working group to discuss the issue of prevention of SCD in youth [38<sup>11</sup>]. This review will attempt to find evidence derived from hundreds of new publications in recent years and identify areas of existing or potential consensus as well as gaps in the knowledge base that require a concerted effort to build evidence and create consensus. Until data are collected and evidence agreed upon, debate, which serves no one, especially the victims of SCA, will continue to dominate this important issue.

## REFRAMING THE SUDDEN CARDIAC DEATH DISCUSSION

SCD is not a disease or medical condition but an outcome of a broad spectrum of diseases. Its prevention requires disease-specific application of known preventive modalities (medication, devices, possible lifestyle modifications) and the ongoing surveillance by a personal medical practitioner. An ECG is a simple test that rarely carries diagnostic properties. Similar to the H&P, it is an early step in a process to establish a definitive diagnosis, using additional testing modalities. It requires confirmation and further evaluation to achieve a final diagnosis in most instances, which is the case with most screening tests. The ECG cannot replace the follow-up evaluation and diagnostic acumen of a trained physician. Further, it does not replace prior medical guidelines and risk stratification developed over decades of medical practice. Thus, the question

**Table 1. Sudden cardiac arrest incidence and prevalence**

References	Study design	Number studied	Age (years)	Risk incidence	Incidence per 100 000 person-years	Source of data
<b>Incidence</b>						
Liberthson [1]	Review of nine studies	469 cases	1–35		1.3–8.5	Nine published papers
Eckart <i>et al.</i> [2]	Retrospective military death review of recruits 1977–2001	US military recruits	18–35	1 : 8000	13	Autopsy based
Corrado <i>et al.</i> [3]	Population-based cohort study	42 386 athletes	12–35	1 : 28 000	3.5–0.4	Veneto Region Registry
Maron <i>et al.</i> [4]	Minnesota athletes 1985–2007	651 695 high school athletes	16–17	1 : 160 000	0.46	Minnesota State High School league (insurance plans) and public media sources
Maron <i>et al.</i> [5]	Registry	1866 athletes surveyed; 1049 cardiac SCD cases	12–35	1 : 200 000	0.6 (2001–2006)	Registry (cases) from: Internet and media and Minneapolis Heart Institute Foundation Research registry and personal reports
Drezner <i>et al.</i> [6]	Survey of arrests in schools with AED	1710 high schools 36 SCA cases; 14 high school students	14–17	1 : 23 000	4.4	High schools with AED in National Registry for AED Use in Sports
Atkins <i>et al.</i> [7]	Prospective population-based cohort of OHCA 2005–2007	624 children OHCA at 11 North American ROC centers	0–19	1 : 27 000	8.04 overall Infants: 72.71; Children: 3.73; Adolescents: 6.37	EMS Registry; OHCA
Chugh <i>et al.</i> [8]	Prospective population-based cohort study/records review in Oregon of OHCA	33 SCD cases	0.03–12.3	1 : 58 000	1.7	EMS records; medical records, autopsy reports
Asif <i>et al.</i> [9**]	NCAA, college athletes 2004–2008	2 million NCAA athletes	17–23	1 : 45 000	2.1	NCAA Resolutions Database, public media reports, and catastrophic insurance claims
Winkel <i>et al.</i> [10] Denmark	Nationwide retrospective study 2000–2006	625 sudden unexpected death cases	1–35	1 : 36 000	2.8	Death certificates, National Patient Registry, autopsy reports
Harmon <i>et al.</i> [11**]	Review of NCAA deaths 2004–2008	273 cases (45 cardiac)	17–23	1 : 43 770	2.28	NCAA Memorial Resolution list, Parent Heart Watch Database
Margey <i>et al.</i> [12*]	Ireland CSO SCD review 2005–2007	116 SCD cases	15–35	1 : 35 000	2.85	Death cert, autopsy, inquest reports
Steinvil <i>et al.</i> [13]	Israeli athletes 1985–2009	24 SCD cases	12–44	1 : 38 000	2.6	Retrospective media search using two newspapers, 1/1985–12/2009
Meyer <i>et al.</i> [14*]	Retrospective cohort review 1980–2009 in King Co., Washington of OHCA	361 SCD cases	0–35	1 : 69 000 (14–24); 1 : 23 000 (25–35)	2.28	EMS records, medical records, death cert, autopsy

**Table 1. (Continued)**

References	Prevalence (%)	Age (years)	Population
Prevalence of conditions associated with sudden cardiac death			
Fuller <i>et al.</i> [15]	0.4	13–19	5617 high school students (United States)
Corrado <i>et al.</i> [3]	0.2	12–35	42 386 athletes (Italy)
Wilson <i>et al.</i> [16]	0.3	10–17	2720 athletes and children (United Kingdom)
Bessem <i>et al.</i> [17]	0.7	12–35	428 athletes (the Netherlands)
Baggish <i>et al.</i> [18]	0.6		510 collegiate athletes (United States)
Maron <i>et al.</i> [19]	0.3	12–35	Competitive athletes

AED, automated external defibrillator; CSO, Central Statistics Office; EMS, emergency medical services; NCAA, National Collegiate Athletic Association; OHCA, out-of-hospital cardiac arrest; ROC, Resuscitation Outcomes Consortium; SCA, sudden cardiac arrest; SCD, sudden cardiac death.

is whether the ECG is more helpful than the current system in providing an efficient and efficacious cardiovascular screening process for youth.

**PURPOSE OF SCREENING**

A central tenet of this discussion is whether the purpose of cardiac screening is to identify those potentially at risk for SCD or only to prevent SCD. Identification allows the application of clinical guidelines and surveillance for changes in symptoms or clinical status. Further, it is known that SCD is the first symptom in a significant number of youth. Given the genetic nature of most of these conditions, identification of one family member may prevent the SCD of another. The analytical framework of the United States Preventive Services Task Force [44], derived from the principles of Wilson and Jungner [45], is to prevent the disease either from occurring or from resulting in death. The problem with the application of these principles to SCD is that it is not a single disease or condition but a possible outcome from many cardiovascular conditions.

**SCREENING METHODS**

The search for a single solution to screening may not be logical, given that some screening methods are more effective for specific conditions and should be discussed in that context. The question remains whether the current system (H&P) is the best overall screening process to identify the greatest proportion of those at risk, or would be improved by the addition of an ECG.

**WHO SHOULD BE SCREENED?**

In the United States, over 92% of all professional athletes receive an ECG, with many having echocardiograms and exercise stress testing [46]. It has been suggested that targeted screening of National Collegiate Athletic Association (NCAA) athletes could provide data regarding the efficacy of screening in younger ages [47], but that recommendation neglects to note that the highest rates of SCA occur during adolescence.

**Screening of those with symptoms**

Previous studies of youth who have experienced SCA note that approximately 50% reported antecedent symptoms and only 16% had a known positive family history [1]. This varies by disease, with 10–30% of those with long QT syndrome and 80% of those with autopsy-negative SCD having SCA as the

first symptom [48,49]. Although a variety of potentially cardiac-related symptoms may have been present in those experiencing a SCA, the specificity of those symptoms for serious conditions is low, and they are often overlooked or dismissed. In a study of 158 athletes who underwent the current preparticipation evaluation using H&P, only 3% who subsequently experienced SCA were suspected of having cardiovascular disease and only one was correctly identified [50].

### Screening of those with positive family history

The majority of conditions associated with SCA have a genetic basis. Most people are not fully aware of important aspects of their family history, making this element a less useful tool. In those with a positive family history, the value of family genetic screening is illustrated by Tan, whose study of family members for genetically inherited conditions after a family death found an additional 8.9 affected individuals [51]. The effective application of genetic screening is a complicated issue and awaits lower costs, protection from discrimination in all areas, increased knowledge of genetic variants, and acceptance of genetic testing by the population.

### Screening of athletes or screening of all children

The majority of states require high school and middle school athletes to undergo cardiac screening in addition to a general evaluation before participating in school sports. In 2011–2012, 7.69 million athletes participated in high school sports in the United States, 58.3% boys and 41.7% girls, with almost 46% of all students participating in sports [52,53]. Screening only high school athletes will miss millions of high school students who do not participate in organized school team sports and those who are younger than 13–14 years of age. Although activity increases the risk of SCA [54], the definition of an athlete as a participant in a 'school team sport' excludes many potentially at risk. Additionally, not all SCA occurs with activity.

### SUDDEN CARDIAC DEATH INCIDENCE AND PREVALENCE

One of the important recommendations of the NHLBI Working Group on SCD was that a prospective population-based SCD in the young registry be developed in collaboration with the Center for Disease Control and Prevention [38<sup>\*\*\*</sup>]. The planning for this process has now been initiated [55]. Yet, the

question remains: is there a critical number of deaths above or below which something or nothing should be done to prevent this occurrence?

One of the major difficulties in determining the incidence of SCD in youth, especially in the United States, is the absence of reliable data on which to base these determinations. Estimates vary widely, with one report, largely based on media information, suggesting an incidence of 0.6/100 000 [5], whereas a report using an NCAA database on athletic deaths showed a much higher incidence of 2.3/100 000 [11<sup>\*\*\*</sup>]. The best incidence data in the United States on children comes from Resuscitation Outcomes Consortium emergency medical services registry, using a metric of out-of-hospital cardiac arrest (OHCA) [7]. This varied by age, with the highest being in infants (72.71/100 000 person-years); in children, 3.73/100 000 person-years; and in adolescents, 6.37/100 000 person-years. The incidence of SCD is greatest in football and basketball, and has been noted to be higher in black athletes and in boys [56]. Drezner *et al.* predicted that between 0.2 and 0.7% of the young population has a condition (Table 1).

### NATIONAL HEART LUNG AND BLOOD INSTITUTE WORKING GROUP

The NHLBI Working Group identified knowledge gaps in the epidemiology and cause of SCD, the performance of the specific screening in a target population, management of asymptomatic heart disease identified by screening, and the impact of a screening program [38<sup>\*\*\*</sup>].

### PRIOR STUDIES ON ECG SCREENING

A number of studies described below indicate the outcomes of screening in various geographies and population groups.

#### Efficacy of ECG to screen for conditions associated with sudden cardiac arrest

Data from Italy have demonstrated that an ECG-based screening can prevent SCD by identifying youth with undiagnosed conditions predisposing to SCA [3]. The ECG is more sensitive in identifying those at risk for SCA than the H&P alone [3,18,35–37,57<sup>\*</sup>].

#### Students in Japan

Mandatory mass ECG screening of school children for cardiovascular disease has been present in Japan since 1973, occurring in the 1st, 7th, and 10th

grades [36]. The greater sensitivity of ECG screening compared with H&P has been documented in studies of Japanese school children [58].

### **Athletes in Italy and Europe**

In Italy, the *Medical Protection of Athletes Act* was passed in 1979. In 1998, Corrado *et al.* [59] reported a study of athletes younger than 35 years who were screened with a history, physical examination, and ECG from 1979 to 1996, with 1.8% of athletes disqualified from competition because of their cardiovascular conditions. The ECG was three times more likely to identify those at risk than the H&P alone [15]. This program decreased incidence of SCA in athletes by 89% over a 25-year period [3].

### **Israel**

A report from an observational study of SCD from 1985 to 2009 aimed to determine whether ECG mandated in a screening program in Israel resulted in fewer SCDs [13]. Retrospective data collection using media reports in two Israeli newspapers ascertained the outcomes. There was no difference in the yearly incidence of 2.6 events/100 000 athlete years, before or after the mandate. The methodology of the study limits its validity, and, thus, its applicability.

### **United States college athletes**

The use of screening in college athletes in the United States varies from one institution to another. Reports from a few selected universities are described below.

#### **Harvard University**

In a report of 510 athletes screened, the ECG, in addition to H&P, improved the overall sensitivity of screening to 90.9% with a negative predictive value (NPV) of 99.8% [18]. Further, the most serious conditions were identified by ECG and not by H&P.

#### **The University of Virginia**

Screening of 1473 athletes over 5 years using an H&P and ECG identified 1.6 times more cardiovascular abnormalities than H&P alone [60]. Only two athletes (0.1%) required disqualification.

#### **University of Kansas**

Screening of 964 consecutive college athletes with ECG and echocardiography found distinct ECG abnormalities in 10%, more in boys (15%) than girls (6%) and more in blacks (18%) compared with whites (8.6%). AHA current participation

physical evaluation guidelines would not have detected 75.8% of these abnormalities [19], which identified 1% with serious conditions. With initial exclusion of 0.93% (nine athletes), only two were eventually excluded from competition.

### **Other screening in youth**

In the United States, screening of youth of the high school student age or younger is regulated by individual states in accordance with their interscholastic rules. Groups noted below have studied this population and their reports are discussed.

#### **Nevada high school athletes**

In the largest United States ECG screening study of 5615 high school athletes in Nevada, the sensitivity of the ECG to identify serious cardiovascular abnormalities was 70 vs. 6% for H&P [15,37]. Overall, only 0.4% of athletes were disqualified from competition.

#### **Philadelphia**

In 2006–2007, 400 healthy children were screened using a personal medical questionnaire, physical examination, ECG, and echocardiography [61]. In this sample, 10 individuals (2.5%) were found to have potentially serious conditions. It was concluded that it is feasible to add the ECG to cardiac screening, but that improved ECG standards using age, sex, race and ethnicity are greatly needed to increase the efficacy of screening in a young population.

#### **Chicago**

Young Hearts for Life reported using ECG screening on 32 561 high school students between 2006 and 2009 [62<sup>¶</sup>]. They identified 2.5% who required further testing, but outcomes were not provided.

#### **State of Texas**

In 2007, a screening program was initiated by the Texas legislature leading to the screening of 2506 students, with 2.3% meeting the criteria for cardiovascular disease; 0.4% eventually received a positive diagnosis [63<sup>¶</sup>]. Only 66% of those identified as potentially at risk followed through with subsequent evaluation. Limited echocardiography had relatively low interobserver agreement of 79%.

## **SPECIFIC STUDIES ON ECG CHARACTERISTICS**

In 2008, Lawless and Best summarized the current state of knowledge regarding interpretation and

diagnostic accuracy of the ECG [64]. They concluded that the ECG improved the sensitivity of the screening process over the H&P alone, but found many concerns and areas of lack of knowledge, including a clear standard for ECG interpretation based on data that would be applicable to a diverse population. False-positives range from 1.9 to 16% with false negatives 4–10% [64–66].

Variations in the ECG have been shown to be related to age, stage of development, especially puberty, sex, racial and ethnic group, type of sport, and degree and type of training. None of the current guidelines take all or even most of these characteristics into consideration.

### Pediatric ECG studies

Pediatric cardiologists use the criteria of Davignon based on 2141 ECGs from white Canadian children published in 1979 [67–69]. As the United States

population becomes increasingly diverse, these normative data do not reflect the current population subgroups. Rijnbeek *et al.* have published new normal standards for Dutch children using current European ECG technology, but these are not used commonly in the United States and do not reflect the diversity of the United States population [70,71]. A monograph on Taiwanese children showed markedly lower voltages when compared with white children [67,72].

### ECG differences by race or ethnicity

Several studies have suggested ECG differences by race and ethnicity. It is important to understand the ethnicity differences to avoid over-diagnosis of cardiomyopathy in athletes of African or Afro-Caribbean descent and to recognize similarities and differences in broad ethnic groups [7,73<sup>\*\*\*</sup>]. Black United States elite football players were twice

**Table 2. Specific ECG abnormalities of concern in youth**

Abnormality	
Amplitude criteria for left ventricular hypertrophy (LVH)	
R wave	R wave only amplitude not associated with true LVH in adults; addition of left atrial enlargement (LAE), left axis deviation (LAD) and ST-T wave changes indicates LVH; data in children unclear
Q wave	Q wave deeper than 3 mm or >40 ms in adults is abnormal. Torso placement of ECG leads exaggerates Q-wave depth
Repolarization	
T waves	
Inversion	T wave inversion in >2 contiguous leads (V1–V4) after puberty of concern for arrhythmogenic right ventricular cardiomyopathy Deep T-wave inversion in African descent may be normal, but in others can suggest left ventricular cardiomyopathy
ST segments	
Elevation	
Brugada	May indicate Brugada pattern with early take off $\geq 2$ mm of downsloping ST segment with negative (coved or saddle back type of T wave in V1 and V2, may mimic right bundle branch block)
J point/ERS	May indicate early repolarization syndrome (ERS) if J point/ST segment morphology is only in inferior leads or ST-segment morphology is horizontal or downsloping instead of ascending or upsloping, which is a benign variant
Depression	
QT interval	Uncommon in children. If $\geq 0.5$ mm in $\geq 2$ leads, consider hypertrophic cardiomyopathy or other cardiomyopathy
Conduction	
Wolff–Parkinson–White syndrome	Absence of Q wave in V6, LAD and short PR interval with delta wave should raise suspicion in children. Pseudo preexcitation can be seen with some congenital heart disease, especially hypoplastic left heart syndrome
Left bundle branch block	Very uncommon in children except with congenital heart disease postoperatively, marked LVH or dilated cardiomyopathy
Atrioventricular block (high grade)	First-degree and second-degree (Type I) atrioventricular block common in young athletes, but Type II second-degree or high-grade block should raise concerns

**Table 3. Test characteristics of ECG and history and physical examination**

Study	Population	Sensitivity H&P (%)	Sensitivity ECG (%)	Specificity H&P (%)	Specificity ECG (%)
Fuller <i>et al.</i> [15]	5615 high school athletes	3–6	60–70	97.8	97.4
Pelliccia <i>et al.</i> [65,76]	32 652 athletes (median 17 years); 4450 athletes (mean 25 years)	–	98.8	–	95.2
Wilson <i>et al.</i> [77]	2720 athletes; 10–17 years	0	100	–	–
Bessem <i>et al.</i> [17]	428 athletes (the Netherlands); 12–35 years	33	67	–	89.1
Baggish <i>et al.</i> [18]	510 college athletes	45.5	90.9	94.4	82.7
Weiner <i>et al.</i> [66]	510 college athletes	45.5	90.9	94.4	89.5
Vetter <i>et al.</i> [61]	400 children; 5–19 years	20	70	42.3	93.1
Magalski <i>et al.</i> [56]	964 university athletes; 18–21 years	44.4; PPV = 1.8, NPV = 99.3	88.9; PPV = 2.7; NPV = 99.9	76.4	69.5
Koch <i>et al.</i> [57*]	343 German athletes; 10–15 years	–	38; PPV = 13; NPV = 88	–	64

H&P, history and physical examination; NPV, negative predictive value; PPV, positive predictive value.

as likely to have abnormal ECGs as whites (30 vs. 13%) [56,74\*]. Ethnicity-based guidelines should improve the ECG specificity [75].

**Differences in athletes’ ECGs**

Highly trained athletes have physiologic adaptations in the cardiovascular and autonomic nervous system that may be manifest on the ECG. These adaptations, which increase the cardiac output and allow enhanced cardiovascular performance, are described

as Athletic Heart Syndrome [78,79]. Pelliccia *et al.* [65] characterized those abnormalities into ‘normal athletic adaptations to exercise’ with true ECG abnormalities of only 4.8%. Subsequent reports with ‘modern’ ECG guidelines further reduce this number [62\*,80,81\*]. Many of these modern ECG recommendations are based on incomplete data with little comparison to a ‘gold standard’ or to follow-up outcomes over time. Sharma *et al.* [82] have reported on 1000 junior elite athletes (mean age 15 years) and found a number of common changes. Uberoi *et al.*

**Table 4. Cost-effectiveness studies**

References	Parameters	ECG	H&P	Echocardiogram
Fuller [37] (High School Athlete Screening)	Cost per life year saved	\$44 000	\$84 000	\$200 000
	Life years gained/ 700 000 screened	92	1080	1232
Tanaka <i>et al.</i> [83] (Japan Schools)	Cost per life year saved	\$8800	–	–
Quaglini <i>et al.</i> [84] (Italian Neonates)	Cost per life year saved	\$18 465	–	–
Wheeler <i>et al.</i> [85] (Decision Model)	Incremental cost-effectiveness per life year saved	\$42 900 (ECG + H&P)	\$76 100	–
	Lives saved	2.1 years/1000 athletes	0.56/1000 athletes	–
Schoenbaum <i>et al.</i> [86*] (Decision Model)	Incremental cost-effectiveness per QALY	\$68 800 (ECG added to H&P and either positive referred) \$37 700 for ECG alone	Includes H&P –	–
	Lives saved per million person cohort	131 for ECG added to H&P and either positive referred 127 for ECG alone	Includes H&P –	–
Halkin <i>et al.</i> [87*] (Cost-Projection Model)	20 year annual US screen overall costs	\$51–69 billion	–	–
	Lives saved	4813 over 20 years	–	–

H&P, history and physical examination; QALY, quality-adjusted life year.

[88<sup>7</sup>] recently suggested that up to 80% of trained athletes will have changes on their ECG that should be considered benign.

regardless of the level of training (Table 2) [64,65, 82,89<sup>8</sup>,90,91<sup>9</sup>,92<sup>10</sup>].

### ECG ABNORMALITIES OF CONCERN IN YOUTH

Several recent reports have clarified abnormalities associated with training and those of concern

### TEST CHARACTERISTICS OF THE ECG

The test characteristics of sensitivity (Sn), specificity (Sp), and positive and negative predictive values (PPV, NPV) reveal limitations in all forms of cardiac screening. A summary of these values for ECG and

Concerns and barriers	Solutions
Low prevalence	Conditions are more common than appreciated Improve identification
Large number of youth	Target population Screen periodically, not yearly (e.g., 7th and 10th grade)
Resource/manpower issues: few physicians available	Use multiple physician specialists [family physicians, pediatric cardiologists, adult cardiologists, pediatricians, internists, sports medicine, physician extenders (nurse practitioners and physician assistants)] Improve computer technology/assistance Incorporate new ECG standards
Lack of infrastructure for screening	Incorporate screening into current athletic preparticipation screening and well child visits Develop screening clinics Use both a school-based and a clinic-based platform
Differences in European and US populations	Differences in prevalence in Europe and United States may relate to differences in identification ECG can identify most of the common conditions in the United States
ECG sensitivity and specificity, false positives, false negatives	New ECG standards by age, race, sex, and ethnicity will improve sensitivity and specificity and decrease false positives Studies needed with gold standard for definitive diagnosis ECG is a screening tool, not a definitive diagnostic tool, as every screening test requires confirmation and further evaluation
Anxiety	To relieve anxiety of false positives, clarification of diagnosis should be quickly accomplished Screening can be structured to obtain most results at initial screen, including echocardiograms, if needed No studies prove anxiety is high in either parents or youth
Disqualification	Few screened have long-term disqualifications Accommodations or different sports can allow some type of athletic participation for most youth Safety-net to allow safe participation for most conditions can be accomplished (AED/CPR availability)
Liability	Indicate scope of screening to families when performed Liability may be applied to failure to screen rather than failure to identify Case law has clarified some of these issues (Knapp, etc.)
Health concerns regarding activity restriction	Restriction from sports is not a given Activity guidelines should be reconsidered to encourage healthy activity
Costs	Several studies suggest that ECG screening may be cost-effective but variable results are found from decision models Real life field cost studies are needed

AED, automated external defibrillator; CPR, cardiopulmonary resuscitation.

H&P screening is shown in Table 3 [15,17,18,56,57<sup>\*</sup>, 61,65,66,76,77].

### TRAINING THOSE WHO READ ECGS

Regarding the accuracy of the ECG for screening purposes, Hill *et al.* [93<sup>\*</sup>] found little agreement among those who read a set of pediatric ECGs. The fallacy of this study is that the readers were requested to make treatment decisions based only on the ECG. It does point out that even ‘trained’ individuals lack basic recognition skills in many instances. Similarly, Viskin *et al.* [94] showed four ECGs to a number of practitioners and found a low level of skill and agreement. Both of these sample sizes and methodologies fail to reach a level that can allow one to generalize their results.

Drezner *et al.* [95<sup>\*\*</sup>] have shown that education of those reading ECGs can improve their agreement with predetermined standards. Thus, it is imperative for data to be derived to indicate if these standards are scientifically rigorous or not.

### COST-EFFECTIVENESS STUDIES

Over a decade ago, Fuller indicated that the use of ECGs improved the cost-effectiveness of pre-participation screening when compared with H&P or echocardiography [37]. Japanese and Italian studies confirmed these impressions [83,84,96]. Using a cost-effectiveness analysis based on a decision model, Wheeler *et al.* [85] concluded that addition of an ECG to H&P for competitive athletes aged 14–22 in the United States may be cost-effective because it would save 2.1 life years per 1000 athletes for an incremental cost-effectiveness ratio of \$42900 per life year saved, which falls into the ‘willingness-to-pay’ category. Other models have suggested moderate to relatively high cost-effectiveness using different assumptions [86<sup>\*</sup>,87<sup>\*</sup>,97<sup>\*</sup>]. H&P has low sensitivity and limited health economic value [15,59] (Table 4) [37,83–85,86<sup>\*</sup>,87<sup>\*</sup>].

### SCREENING CONCERNS, BARRIERS, AND SOLUTIONS

Despite very compelling data from Italy, several concerns have been raised that indicate potential barriers to ECG screening in the United States with regard to feasibility, logistics, and costs [19,33<sup>\*\*</sup>,98<sup>\*</sup>]. Table 5 identifies concerns that have been raised and proposes solutions.

Those with true medical conditions identified by screening enter the clinical arena and are treated as others with the condition. The somewhat bothersome caveat here is that we are now being forced to think about and develop strategies for

those who are asymptomatic at the time of presentation. The ‘asymptomatic’ label does not mean that this person will always be asymptomatic; our ability to determine who will become a higher-risk individual is limited at this time and will only be solved by long-term sequential prospective studies of those identified while still asymptomatic.

The scientific community needs more complete and rigorous research as recommended by the NHLBI to settle this debate or, at least, to augment the knowledge base.

### CONCLUSION

Risk stratification to determine who will have a SCA is imperfect with limited data to link early detection with decreased mortality: a randomized study would require 4 million person-years to show an effect of intervention [38<sup>\*\*</sup>]. Although screening with an ECG does not have the weight of randomized trials that prove it can prevent SCD, it has been shown to identify at-risk youth and should be considered a good first step. General medical principles indicate that we can prevent death in these populations once the individuals are treated by standard medical practices. Thus, it is logical to consider that any method that can identify at-risk individuals and allow us to use already practiced interventions should play a role in preventing deaths.

Preventive medicine leaves little footprint or takes decades to do so, making some feel that it is a lightweight endeavor, not as worthy as the obvious triumphs of a cured cancer or infection, or even of a corrected congenital heart defect. Although the concerns and downstream effects of any screening process should be carefully scrutinized and adverse effects prevented, there is insufficient evidence that our current system works or that an ECG-based system would not work.

We should continue to study screening to determine the best methods to identify at-risk youth so that, one day, we will have sufficient data to determine the best ways to screen, on whom, and how to do it, using best practices. We should remove obstacles, stop debating, as no one wins, especially our children and athletes, and we should start working together to develop the evidence base that we all desire. At that point, our consensus will be accomplished.

### Acknowledgements

None.

### Conflicts of interest

There are no conflicts of interest.

## REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
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Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 262–263).

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The authors express their support for ECG screening indicating that identification of disorders that predispose to SCD can be best accomplished by the use of an ECG. They suggest that manpower to read ECGs is the major obstacle to ECG screening and propose education of physicians in ECG reading to eliminate this manpower shortage.

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- 87.** Halkin A, Steinvil A, Rosso R, *et al.* Preventing sudden death of athletes with electrocardiographic screening: what is the absolute benefit and how much will it cost? *J Am Coll Cardiol* 2012; 60:2271–2276.

This study used a cost-projection model with assumptions from Italian data and estimates from the Medicare reimbursement database for costs. They suggest that a 20-year annual program of ECG screening of young competitive athletes in the United States would cost between \$51 and \$69 billion and would save 4813 lives. They calculated that the cost per life saved is likely to range between \$10.6 and \$14.4 million. The assumptions overwhelm the model and make its applicability to the real world questionable.

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This article presents the consensus opinions of experts on the ECG findings associated with athletic training and those that are abnormal. An excellent figure uses pictorial descriptions to illustrate many of these points.

- 89.** Wilson MG, Sharma S, Carre F, *et al.* Significance of deep T-wave inversions in asymptomatic athletes with normal cardiovascular examinations: practical solutions for managing the diagnostic conundrum. *Br J Sports Med* 2012; 46 (Suppl 1):i51–i58.

This manuscript provides a systematic review of T-wave inversion in athletes and discusses the relationship of this finding to sudden cardiac arrest associated conditions including hypertrophic cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy. The goal is to help identify young athletes at risk.

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This study describes the ECG findings in 152 under-18 elite African soccer players who showed many ECG abnormalities, including increased R/S-wave voltage, ST-segment elevation, and deeply inverted or diffusely flat T waves. LV remodeling in African athletes showed a disproportionate wall thickening compared with whites but had similar cavity size. There were distinctive patterns in African athletes by country and ethnicity.

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This paper reviews the recent concerns about early repolarization syndromes and helps distinguish benign early repolarization patterns from more malignant early repolarization patterns. They suggest an ECG registry to learn more about this complicated issue.

- 93.** Hill AC, Miyake CY, Grady S, Dubin AM. Accuracy of interpretation of preparticipation screening electrocardiograms. *J Pediatr* 2011; 159:783–788.

This study had 53 members of the Western Society of Pediatric Cardiologists interpret 18 ECGs with no additional clinical information and make decisions as to the normality of the ECG as well as decisions regarding activity restrictions. The sensitivity for recognition of an abnormality was 68% and the specificity 70%. Sports participation was 'accurately' permitted in 74% and appropriately restricted in 81%. The fallacy of this study is that it attributes more 'decision-making' qualities to the ECG interpretation than should be so designated in a real-world clinical decision-making process wherein more clinical information is utilized. It does point out that ECG reading skill levels could be significantly improved.

- 94.** Viskin S, Rosovski U, Sands AJ, *et al.* Inaccurate electrocardiographic interpretation of long QT: the majority of physicians cannot recognize a long QT when they see one. *Heart Rhythm* 2005; 2:569–574.

- 95.** Drezner JA, Asif IM, Owens DS, *et al.* Accuracy of ECG interpretation in competitive athletes: the impact of using standardised ECG criteria. *Br J Sports Med* 2012; 46:335–340.

A study of 60 physicians showed that ECG reading skills can be significantly improved when the readers are provided with standardized ECG reading educational materials. Noncardiologists performed as well as cardiologists after education with the ECG criteria tool.

- 96.** Schwartz PJ. Pro: Newborn ECG screening to prevent sudden cardiac death. *Heart Rhythm* 2006; 3:1353–1355.

- 97.** Leslie LK, Cohen JT, Newburger JW, *et al.* Costs and benefits of targeted screening for causes of sudden cardiac death in children and adolescents. *Circulation* 2012; 125:2621–2629.

The authors developed simulation models incorporating detailed prevalence, sensitivity and specificity, and treatment algorithms to determine the cost-effectiveness of targeted SCD screening for hypertrophic cardiomyopathy, Wolff-Parkinson-White or long QT syndrome. Their model indicated that the incremental cost-effectiveness of screening is \$91 000 to \$204 000 per life-year saved. The greatest impact on estimated cost-effectiveness resulted from the assumed disease prevalence, baseline mortality, and the relative risk of mortality resulting from stimulant medication use and sports participation.

- 98.** Estes NA III, Link MS. Preparticipation athletic screening including an electrocardiogram: an unproven strategy for prevention of sudden cardiac death in the athlete. *Prog Cardiovasc Dis* 2012; 54:451–454.

The manuscript describes the authors' opinions about ECG screening. They suggest that the best strategy to save athletes is to improve secondary prevention with better resuscitation once the arrest occurs.