If we had the requisite wisdom or irrefutable evidence to answer the existing questions about screening and the prevention of sudden cardiac death (SCD) in youth, perhaps the perpetual screening debate would be resolved. Without that seemingly inaccessible goal, we continue to discuss and debate the best practices to identify those with conditions that predispose to SCD.1–4

Response by Friedman p 697

This article will attempt to discuss many of the unanswered questions surrounding screening and to present a cogent rationale for the use of the ECG in screening for heart conditions in the young. Only focusing on the How precludes an understanding of the broad focus that is necessary for effective screening for these somewhat elusive conditions in an age group that is changing on a daily basis.

The issues to be discussed in this article will focus on screening data that currently exist, both in the United States and in other countries. A more expansive view of screening of all infants, children, and adolescents, not just athletes, will be proposed along with the advantages and disadvantages of ECG screening.

Why Is Screening Needed?

Many of the condition responsible for SCD are subtle and not evident. SCD is not a disease or medical condition but an outcome of a broad spectrum of diseases or conditions.

To prevent SCD, a predisposing disease condition must be identified and early intervention provided. Disease-specific prevention must be applied with ongoing surveillance by the individual’s physician.

Why Screen Children?

Sudden cardiac arrest (SCA) is not well recognized as an event that occurs in neonates and all children because there is no current registry that documents all childhood SCDs or all childhood cardiovascular deaths. Sudden infant death syndrome (SIDS) may be associated with SCA from channelopathy or with critical congenital heart disease. Many children are extremely active, sometimes even more so than athletes, despite not being involved in an organized team sport. Even when the activity is not part of an organized scholastic event, it is often very competitive.

SCA or SCD in the young often occurs unexpectedly, without warning or recognition of warning symptoms with a reported incidence of 0.6 to 8/100,000.5–7 The prevalence of conditions that cause SCD is estimated to be 0.2% to 0.7% with many of these being silent or undiscovered until a SCA occurs.4 SCA may be the first symptom in up to 50% of children.5,7 A working group, convened by the National Heart, Lung, and Blood Institute to discuss the prevention of SCD in youth, identified a number of knowledge gaps, including (determining) the true incidence of SCD and changes...
associated with screening, prevalence of SCD conditions, time and frequency of screening, targeted or nontargeted screening, outcomes of those excluded from sport or accommodations to allow sport to continue, and the natural history of conditions identified by screening in asymptomatic individuals.10

In the young, SCA is associated with structural and electric cardiac abnormalities, including hypertrophic cardiomyopathy (HCM), arrhythmogenic right ventricular cardiomyopathy, long QT syndrome (LQTS), other electrophysiological conditions including Brugada syndrome, Wolff-Parkinson-White syndrome, catecholaminergic polymorphic ventricular tachycardia, coronary artery anomalies, congenital heart defects, myocarditis, Marfan syndrome, and others.11 It has been estimated that 10% to 15% of cases labeled as SIDS are actually related to channelopathies.12,13

SCA is the major cause of death in young athletes with death reported to occur with or shortly after exercise in 80% of athlete deaths.9

What Is the Purpose of Screening in Children?

A difficult issue that confounds the discussion about ECG screening is whether the purpose of cardiac screening is to identify those potentially at risk for a SCA or only to prevent SCD. Ultimately, we all want to prevent SCD, but we cannot prevent what we do not see. Identification allows the application of clinical guidelines with surveillance for changes in symptoms or clinical status.

There is no evidence that current screening practice of using history and physical examination (H&P) alone is decreasing the overall occurrence of SCD.14 Screening with an ECG has been shown to identify at-risk youth and should be considered a good first step, but it cannot be considered definitive because additional testing often is required for diagnostic confirmation. We know from multiple clinical reports that death in individuals with SCD-related conditions can be prevented once treatment using standard medical practices is initiated. It is logical to consider that any method that identifies at-risk individuals allows us to use recommended interventions to prevent death.

Reports of ECG Screening in Youth

ECG Screening of Newborns in Italy

Schwartz reported on a newborn ECG screening program to identify prolonged QT intervals.15,16 Of 33,000 neonates studied, half of 24 infants who died of SIDS had QTc of >0.44 s with 4 ≥0.46 s.15 Molecular genetic studies have shown that >10% of SIDS cases have functionally significant genetic variants or mutations in LQTS genes.12,17 The Italian neonatal screening program also showed an incidence of prolonged QTc >0.47 s of 0.07% and identified a LQTS mutation in 50% of those genotyped with QTc intervals of >0.46 s.16 Early identification and treatment has the potential to provide lifetime protection for those identified with LQTS. Additionally, identification of a neonate can lead to the identification of multiple family members and could prevent SCD in these individuals.18

ECG Screening in Japan

Mass screening of school children for cardiovascular disease by using an ECG has been mandatory in Japan in the first, seventh, and tenth grades since 1973, indicating a greater sensitivity of ECG screening in comparison with the H&P.19,20 This screening was performed on all school children, irrespective of athletic participation. Approximately 2.7% of Japanese students required additional evaluation and testing after an ECG, with high-risk conditions identified in 0.024% of students.

Screening of All Youth in the United States

Philadelphia Clinic-Based Screening

In 2006 to 2007, we screened 400 healthy children at The Children’s Hospital of Philadelphia using a personal medical questionnaire, physical examination, ECG, and echocardiography.21 Ten individuals (2.5%) were found to have potentially serious conditions.

Children’s Hospital of Philadelphia Community-Based Screening

Since 2006, we have screened >4000 children using an ECG-based system with a personal and family history questionnaire at a school or recreation center gymnasium. Those with abnormal personal or family history or abnormal ECGs receive an immediate onsite echocardiogram (5%–7%) along with a cardiac examination, and 2% to 3% are referred for additional testing such as exercise stress testing, more extensive echocardiography, or other testing. There is a positive rate of 0.7% for true significant conditions from this ECG-based screening.

Chicago

Marek reported using ECG screening on 32,561 high school students from 2006 to 2009.22 With the use of the Corrado criteria, 2.5% were identified as requiring further testing.23

Texas

A screening program evaluated 2506 students with a H&P, ECG, and limited echocardiogram.24 The ECG was abnormal in 2.3% with many false-positive results by history. Only 0.4% eventually received a positive diagnosis and 66.7% did not return for follow-up, including one-third of those suspected of HCM after ECG and echocardiogram.

Screening of Young Athletes in the United States

Nevada High School Athletes

In a study of 5615 high school athletes in Nevada, adding an ECG to the standard H&P, the sensitivity of the ECG to identify serious cardiovascular abnormalities was 70% versus 6% for H&P.25,26

North Carolina High School Screening

A total of 2017 high school athletes were screened with H&P, ECG, and echocardiogram. The H&P was abnormal in 14.7% in comparison with 3.1% abnormal ECGs by using modern criteria. Five SCD-related conditions were found; all were identified by ECG and only 2 by H&P. The
false-positive rate for H&P was 14.5%, and for ECG the false-positive rate was 2.8%.27

Screening Athletes in Colleges in the United States

The test characteristics of the ECG in screening youth including college athletes are shown in Table 1.28–35

ECG Screening of Athletes Outside the United States

Italy

Of 42,386 athletes screened between 1979 and 2004 (age, 12–35 years), the annual incidence of SCA in athletes decreased by 89% (from 3.6/1000 person-years to 0.4/1000 person-years) with only 2% of athletes disqualified.6 Of 33,735 athletes 12 to 35 years of age, screened with a H&P and ECG, 22 (0.07%) had HCM with only 23% having a positive family history or a cardiac murmur; the ECG was 3 times more likely to identify those at risk than the H&P alone.36 The efficacy of the screening program to identify HCM or other cardiac conditions was evaluated by subsequently performing echocardiograms on 4450 previously screened athletes, indicating a low false-negative rate of 1.2%.28

Israel

A retrospective data collection to determine if ECGs mandated in a screening program resulted in fewer SCDs used reports from 2 Israeli newspapers from 1985 to 2009.37 Although, there was no difference in the yearly incidence of 2.6 events/100 000 athlete years, before or after the mandate, it is unclear if the methodology of the study has provided complete data on all deaths.38

Although these reports suggest that screening for SCA with ECG may be more effective than the current system in place in the United States, a large-scale randomized, controlled trial of an ECG screening program versus history and physical examination alone has not been implemented or tested to date and may be prohibitive because 4 million person-years are required to prove efficacy in the prevention of SCA owing to its relatively low incidence.10

Table 1. Comparison of History and Physical Examination and ECGs

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuller25 1997</td>
<td>5615 high school athletes</td>
<td>3–6%</td>
<td>60%–70%</td>
<td>97.8%</td>
<td>97.4%</td>
<td>5.5%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Pelliccia28 2006</td>
<td>32,652 athletes (median, 17 y)</td>
<td>–</td>
<td>98.8%</td>
<td>–</td>
<td>95.2%</td>
<td>8.9% (both ECG and H&amp;P)</td>
<td></td>
</tr>
<tr>
<td>Pelliccia29 2007</td>
<td>4450 athletes (mean, 25 y)</td>
<td>–</td>
<td>98.8%</td>
<td>–</td>
<td>95.2%</td>
<td>11.8% (ECG)</td>
<td></td>
</tr>
<tr>
<td>Magalski30 2008</td>
<td>964 university athletes (18–21 y)</td>
<td>44.4%</td>
<td>88.9%</td>
<td>76.4%</td>
<td>69.5%</td>
<td>22.8% (abnormal history)</td>
<td>9.9% (very abnormal ECG)</td>
</tr>
<tr>
<td>Wilson31 2008</td>
<td>2720 athletes (UK) (10–17 y)</td>
<td>0%</td>
<td>100%</td>
<td>–</td>
<td>6%</td>
<td>1.5%</td>
<td>4%</td>
</tr>
<tr>
<td>Bessert32 2009</td>
<td>428 athletes (Netherlands; 12–35 y)</td>
<td>33%</td>
<td>67%</td>
<td>–</td>
<td>89.1%</td>
<td>5.3%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Baggish33 2010</td>
<td>510 US college athletes (≥18 y)</td>
<td>45.5%</td>
<td>90.9% (ECG+H&amp;P)</td>
<td>94.4%</td>
<td>82.7%</td>
<td>6%</td>
<td>16%</td>
</tr>
<tr>
<td>Weiner and</td>
<td>510 US college athletes (≥18 y)</td>
<td>45.5%</td>
<td>90.9% (ECG+H&amp;P)</td>
<td>94.4%</td>
<td>89.5%</td>
<td>6%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Baggish34 2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vetter35 2011</td>
<td>400 US children (5–19 y)</td>
<td>20%</td>
<td>70%</td>
<td>42.3%</td>
<td>93.1%</td>
<td>23.5% for symptoms</td>
<td>7.8%</td>
</tr>
<tr>
<td>Koch36 2012</td>
<td>343 German athletes (10–15 y)</td>
<td>–</td>
<td>43%</td>
<td>–</td>
<td>64%</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

FN indicates false-negative; FP, false-positive; H&P, history and physical examination; NPV, negative predictive value; and PPV, positive predictive value.
Who Should Be Screened?

Neonates
We propose that all neonates be screened at 1 month of age at their well-child checkup with an ECG that could be read by the pediatrician or using an educational guide similar to that developed in Europe,39 or forwarded to a pediatric cardiologist for reading if the pediatrician does not have the requisite skills. This screening would most likely only identify electric conditions such as LQTS or undiagnosed congenital heart defects.

All Children and Youth
We further propose that all children have age level–appropriate screening that could be performed initially by their primary care doctor with an ECG. The ECG could be read by the pediatrician or sent to a pediatric cardiologist through electronic transmission available in current ECG machines. To select the official high school athlete as the only one who needs or deserves special attention is neither ethical nor medically acceptable.

Athlete Screening
The majority of states require high school athletes to undergo cardiac screening in addition to a general evaluation before participating in school sports. In 2012 to 2013, 7.71 million athletes participated in high school sports in the United States, 58.2% male and 41.8% female, comprising 48% of all high school students.40–42 Screening only high school athletes will miss >47.6 million students who do not participate in organized high school team sports or who are younger than 13 to 14 years of age. Although activity increases the risk of SCA,43 requiring participation in a school team sport excludes many other children potentially at risk. During childhood, participation in team sports varies from 1 year to another, but activity remains a constant, whether it is on an official team or not. Furthermore, not all SCA occurs with activity or during the particular sport practice or competitive event.

Current Screening Recommendations

AHA Statements on Preparticipation Screening in Athletes
In 1996, the American Heart Association (AHA) recommended a 12-element preparticipation screening history and physical examination aimed at high school athletes.44 The preparticipation H&P is not standardized and screening by H&P alone has been limited by inconsistencies in the personnel and forms used.45 At latest report, only 3% of states were using all 12 AHA elements in their forms, and nonphysician personnel such as chiropractors were allowed to perform the preparticipation evaluations in 35% of states. The AHA Scientific Statement: Update 2007 recommended no substantive changes, but raised concerns regarding adding an ECG to the screening process, and did not recommend its use.46 On the other hand, the AHA Update 2007 indicates that "customary screening practices in the US [history and physical examination] may be encumbered by substantive false-negative results…with low sensitivity and specificity for detection of many cardiovascular abnormalities pertinent to young athletes.” It further states that "detection of HCM by the standard screening examination [history and physical] may be unreliable” and that LQTS will not be identified unless “selected items in the personal and family history” are positive. The AHA Statement notes that ECGs are abnormal in >90% of patients with HCM and arrhythmogenic right ventricular cardiomyopathy and can detect ion channelopathies such as LQTS and Brugada syndrome.

Recommendations of European Society of Cardiology on Preparticipation Screening of Athletes and International Olympic Committee
In 2004 and 2005, the International Olympic Committee Medical Commission and European Society of Cardiology, respectively, recommended a screening program for young athletes based on the 12-lead ECG in addition to the H&P.47,48

Is There One Best Screening Method?
The search for a single method of screening may not be logical, given that specific screening methods are more effective for particular conditions. If one is forced to choose, the H&P alone does not appear to identify the greatest proportion of those at risk; it is improved by the addition of an ECG, which is more sensitive in identifying those at risk for SCA than the H&P alone.4,10,26,49

When Should We Do the Screening?
Guidelines to direct the frequency of ECG screening on an individual or the likelihood of a positive test once a negative screening ECG has been obtained have not been developed. Given the developmental changes in the cardiovascular system that occur with growth, a single screening may not be sufficient. A systematic sequential screening including an ECG could be used, perhaps as a neonate to identify those at risk of a LQT mutation related to SIDS or an undiagnosed congenital heart defect; on school entry and in middle school; and once in high school. If one uses an ECG-based screen of all children at a particular age or grade level, participation in a team sport will not determine eligibility for screening. This would make the process more equitable and less complicated overall. An interim H&P for children/athletes could be used in the non-ECG screening years and for noncardiac system screening. To determine the best ages for intermittent screening, studies should be performed.

Where Should Screening Be Performed?
A complete evaluation that includes an ECG can be done in an outpatient clinic office of a pediatrician, family medicine doctor, internist, a pediatric or adult cardiologist, or a sports
What Are the Problems With the Current Screening System of H&P Alone?
If one uses just a H&P, only the small number with positive symptoms or history, and an abnormal physical examination will be identified. Unfortunately, only 50% of youth who have experienced SCA describe antecedent symptoms and only 16% know of a positive family history. The electrical causes of SCD will not have positive physical findings and cardiomyopathies may not. SCA is the first symptom in 10% to 30% of those with LQTS and in 80% of those with autopsy-negative SCD. Cardiac-related symptoms may have been present in those experiencing a SCA, but the specificity of those symptoms for serious conditions is low, leading to their being overlooked or dismissed. This problem is illustrated by a study of 158 athletes who underwent the current preparticipation evaluation by using H&P with only 3% of those who subsequently experienced SCA suspected of having cardiovascular disease and only one identified correctly. Attempts to improve the current system in the United States have focused on feasibility, logistics, and resources. The pediatric medical home (pediatric or family physician office) may best serve this process.

What Are the Concerns, Barriers, and Solutions to the Addition of ECG Screening for Athletes and to the Inclusion of ECG Screening for All Youth Including Neonates?
Several concerns have been raised regarding barriers to ECG screening in the United States focused on feasibility, logistics, and costs and are discussed below, along with potential solutions.

Low Prevalence With Large Numbers of Youth to be Screened
The conditions that cause SCD are uncommon, resulting in a low positive predictive value of screening. Most states have mandated athlete screening; it makes sense to use the best methodology and to extend screening to all children including neonates. With regard to the large numbers of children, a yearly ECG would not be necessary, but could be obtained at selected intervals.

Resources/Manpower Issues
Although we have fewer physicians per population than other countries who use ECG screening and fewer physicians who are focused just on the athlete, we have many more personnel who assist physicians than in many other countries. An effective and organized system with periodic selected use of the ECG can overcome manpower concerns. We can expand the reading of ECGs beyond cardiologists, as pediatricians, family physicians, sports medicine doctors, adult cardiologists, or physician assistants and nurse practitioners can learn to read pediatric ECGs. Clear guidelines could be developed to assist in ECG reading, and many groups have started this effort.

Training Those Who Read ECGs
Hill found little agreement among those who read a set of pediatric ECGs regarding the accuracy of the ECG for screening purposes. The flawed nature of this study is that the readers were requested to make treatment decisions based only on the ECG; however, trained individuals lacked basic recognition skills, emphasizing the need for education. Similarly, Viskin found a low level of skill and agreement among practitioners shown ECGs. The sample sizes and methodologies of these 2 studies preclude the generalization of results. Education of those reading ECGs was shown to improve agreement with predetermined standards.

Lack of Infrastructure for Screening
Criticisms that cite a lack of infrastructure to perform ECG screening fail to recognize that facilities, equipment, and infrastructure already exist within our current medical system. An ECG could be appended to existing well-child visits or to sports evaluations performed in clinics or doctors’ offices or large-scale school screening events. Although an entirely new system does not need to be created, the procedures for the addition of ECG screening would need to be applied to young populations. The pediatric medical home (pediatric or family physician office) may best serve this process.

ECG Standards, Test Characteristics Including Sensitivity and Specificity
The ECG can identify conditions that are responsible for at least two-thirds of SCA in the young with coronary artery anomalies being the most prominent exception. Pediatric cardiologists use the criteria of Davignon from 1979, based on 2141 ECGs from white Canadian children. As the US population becomes increasingly diverse, these normative data do not reflect the current population subgroups; differences in the ECG have been shown to be related to age, sex, race and ethnicity, stage of development, especially puberty, specific sport, and intensity of training. Several studies show ECG differences by race and ethnicity that could lead to the overdiagnosis of cardiomyopathy in athletes of African or Afro-Caribbean descent. Further, black US elite football players are twice as likely to have abnormal ECGs as white US elite football players (30% versus 13%). Pelliccia characterized “normal athletic adaptations to exercise in highly trained athletes” and found true ECG abnormalities in only 4.8%. Several reports have clarified findings associated with training or identified concerns regardless of the level of training. Modern ECG guidelines have been shown to improve specificity and reduce false positives.

Test Characteristics of the ECG in Comparison With the H&P
An ideal screening test will have no false positives or false negatives, identifying all individuals who have the condition and none who do not. It is well recognized that neither the ECG nor the H&P will ever fit these criteria, but the ECG has a relatively high sensitivity and specificity in youth in comparison with the H&P. False negatives range from 4% to
Vetter
ECG Screening of All Youth

10% with false positives ranging from 1.9% to 16%.29,34 The test characteristics for ECG and H&P screening are shown in Table 1. As illustrated in Table 1, with the use of the same 510 subjects, but different ECG reading guidelines, the specificity of the ECG improved from 82.7% to 89.5%, decreasing the false positives.33,34 Scientifically validated ECG reference standards by age, sex, race, ethnicity, and levels of activity with improved computer algorithms should be developed to help decrease the false positives and improve the ECG test characteristics in a similar fashion to this study.

Using modern ECG criteria for reading, Marek decreased referral for additional tests in 32,561 high school students to 2.5%.22 Our community ECG screenings only result in a 2% to 3% referral for additional testing, as well. When screening all children, the abnormalities associated with high levels of athletic training are less likely to be present. To avoid false positives in this population, the reader must be well acquainted with age-related norms that are available.

**ECG Screening Efficacy**

Maron reported that HCM subjects are likely to have abnormal ECGs in 95% of the individuals.9 In arrhythmogenic right ventricular cardiomyopathy, the ECG is abnormal in up to 80%.70 Most with Wolff-Parkinson-White syndrome have abnormal ECGs. Distinguishing the slightly prolonged QTc interval from an abnormal interval associated with a LQT gene mutation can be challenging. Similarly, a portion of the LQTS population will have normal QTc intervals and will be missed, but up to 85% to 90% can be identified by ECG screening.

Most with coronary artery abnormalities have normal resting ECGs. Depending on the individual’s age, abnormal ECGs may identify unsuspected congenital heart defects including the anomalous origin of the left coronary from the pulmonary artery and coarctation of the aorta, among others.

**Identification of Asymptomatic Individuals**

This is one of the least understood aspects of screening, because it is unknown what will happen to young individuals identified before they develop symptoms. The asymptomatic label does not mean that symptoms will never occur; our ability to determine who will become a higher-risk individual is limited and will only be solved by long-term studies of those individuals.

### Table 2. Cost-Effectiveness

<table>
<thead>
<tr>
<th>Report</th>
<th>Parameters</th>
<th>ECG</th>
<th>H&amp;P</th>
<th>Echocardiogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanaka24 (Japan Schools)</td>
<td>Cost per life-year saved</td>
<td>$8800</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fuller29 (high school athlete screening at 13–19 y)</td>
<td>Cost per life-year saved</td>
<td>$44 000</td>
<td>$84 000</td>
<td>$200 000</td>
</tr>
<tr>
<td></td>
<td>Life-years gained/700 000 screened</td>
<td>1080</td>
<td>92</td>
<td>1232</td>
</tr>
<tr>
<td>Quaglini82 (Italian neonates)</td>
<td>Cost per life-year saved</td>
<td>$18 465</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Wheeler83 (decision model on high school and college athletes, 14–22 y)</td>
<td>Incremental cost-effectiveness per life year saved</td>
<td>$42 900 (EGG+H&amp;P)</td>
<td>$76 100</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Lives saved</td>
<td>2.1 y/1000 athletes</td>
<td>0.56/1000 athletes</td>
<td>–</td>
</tr>
<tr>
<td>Schoenbaum85 (decision model on athletes entered at 14 y)</td>
<td>Incremental cost-effectiveness per QALY</td>
<td>$68 800 for (ECG added to H&amp;P and either positive referred)</td>
<td>$37 700 for ECG alone</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Lives saved per million person cohort</td>
<td>131 lives saved for strategy with ECG added to H&amp;P</td>
<td>127 lives saved for strategy with ECG alone</td>
<td>–</td>
</tr>
<tr>
<td>Anderson and Vetter71 (transition Markov model on all children entered at 12 y)</td>
<td>ICER/LYS (HCM, LQTS)</td>
<td>$41 400 (EGG+H&amp;P)</td>
<td>Includes H&amp;P</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Lives saved</td>
<td>3.4/1000 screened</td>
<td>Includes H&amp;P</td>
<td>–</td>
</tr>
<tr>
<td>Leslie79 (Markov simulation model on 8 y olds with ADHD and 14 y olds in sports)</td>
<td>ICER/LYS (WPW, HCM, LQTS)</td>
<td>$90 828</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Lives saved</td>
<td>1.9/1000 screened</td>
<td>Includes H&amp;P</td>
<td>–</td>
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</table>

H&P indicates history and physical examination; ICER, incremental cost-effectiveness ratio; LYS, life-year saved; and QALY, quality-adjusted life-year.

### Table 3. ECG Screening

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
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</thead>
<tbody>
<tr>
<td>Higher sensitivity than history and physical</td>
<td>More false positives than history and physical</td>
</tr>
<tr>
<td>Lower costs with higher cost-effectiveness than other models</td>
<td>Additional testing adds costs</td>
</tr>
<tr>
<td>First step in diagnostic pathway</td>
<td>Additional testing required for diagnosis</td>
</tr>
<tr>
<td>Interpretation can be taught to wide range of healthcare professionals</td>
<td>Current standards do not recognize differences by age, sex, race/ethnicity</td>
</tr>
<tr>
<td>Technological assistance possible using computer measurements and algorithms</td>
<td>Current computer readings not always correct</td>
</tr>
</tbody>
</table>
who are identified while asymptomatic. This is actually a major factor in the cost-effectiveness of ECG screening in an economic model developed to evaluate the drivers of cost.\textsuperscript{71}

**Disqualification**

Few screened will have long-term disqualifications and those will be determined by current standards such as the Bethesda criteria that are specific for the condition identified.\textsuperscript{72}

**Liability**

The scope and limitations of screening, regardless of the screening method, should be explained to those being screened and to their families. It is an opportunity to educate regarding the warning signs and symptoms that can precede a sudden cardiac event. It has been suggested that, in the future, liability may be applied to failure to screen or inform parents about ECG screening.\textsuperscript{73} Case law has clarified some of these issues, especially the Knapp case.\textsuperscript{74,75}

**Health Concerns Regarding Activity Restriction**

Increasingly, studies are suggesting that strict prohibition of activity for most conditions associated with SCD may not be necessary.\textsuperscript{76,77} Accommodations and assurance that playing fields and sports arenas are safe by having personnel trained in cardiopulmonary resuscitation and placing automated external defibrillators in all sites where young people gather to play sports or participate in activity will enhance the ability to avoid activity restrictions.

**Costs and Cost-Effectiveness**

Various reports have suggested acceptable, moderate, or relatively high cost-effectiveness of the ECG by using different assumptions as shown in Table 2.\textsuperscript{26,71,78–83}

On the other hand, the H&P has low sensitivity and limited cost-effectiveness.\textsuperscript{26,36} Finding genetic conditions allows necessary.\textsuperscript{76,77} Accommodations and assurance that playing fields and sports arenas are safe by having personnel trained in cardiopulmonary resuscitation and placing automated external defibrillators in all sites where young people gather to play sports or participate in activity will enhance the ability to avoid activity restrictions.

**Steps Toward a Best-Practice Model**

A best-practice model should address the major barriers to implementing ECG screening on a large-scale basis including manpower considerations; the logistics of adding an ECG to a neonatal, well-child, or athletic evaluation; and the costs of the process.

We have personally been involved in clinic-based, and in community-based screening in schools and recreation centers. Our screening studies have shown that it is feasible to screen a population of school-aged children by using an ECG and that a methodology for use of either a medical office or the school as a screening facility is not difficult to develop.\textsuperscript{21} A greater number of participants can be reached more efficiently by providing screening at the school. However, this requires the capacity to move resources, including personnel and equipment, into schools and to develop a screening team integrating the school and medical personnel. Reserving echocardiograms for those with abnormal ECGs or with an H&P suggestive of a structural or functional cardiac condition seems to be the most cost-effective methodology to use until additional data regarding ECG efficacy and effectiveness are obtained. An example of resources required for a clinic- or community-based ECG screening are shown in Table 4. These resources will vary according to the specific screening system or group.

**Summary and Conclusions**

We should categorically strive to find the best methods to prevent SCD in the United States. The current system of screening only athletes has not achieved the goal of decreasing SCD in youth. A good first step is the recent effort by the National Institutes of Health in partnership with the US Centers for Disease Control and Prevention to fund a small number of states in a pilot project to collect information on sudden deaths, including cardiovascular deaths to develop a national registry of these deaths as recommended by the National Heart, Lung, and Blood Institute Working Group on SCD.\textsuperscript{10} Support of screening efforts with sound scientific rigor should be developed to determine the best methods to identify young children before they experience a SCA or SCD and intervene to prevent such occurrences. Current screening efforts should be directed at collecting data in a systematic fashion with standardized criteria for the screening process, including improving ECG test characteristics and reading skills. Screened individuals, whether positive or negative, should be tracked. Screening efforts that focus on quantity, not quality, regardless of the screening methodology used, do not advance the

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**Table 4. Example of Potential Resources Needed to Screen 100 Youth**

<table>
<thead>
<tr>
<th>Locations</th>
<th>School Building/Gymnasium/ Training Rooms/Medical Clinic Rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daily personnel</strong></td>
<td></td>
</tr>
<tr>
<td>1 MD</td>
<td>2 ECG techs</td>
</tr>
<tr>
<td>1 nurse manager or coordinator</td>
<td>1 ECHO tech</td>
</tr>
<tr>
<td>1–2 nurses/medical assistants if height, weight, blood pressure obtained</td>
<td>(2–3 h if ≤10% receive ECHO)</td>
</tr>
<tr>
<td>3–4 volunteers (optional but preferred for optimal flow)</td>
<td>3–4 ECHOs/h/tech</td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
</tr>
<tr>
<td>2–3 ECG machines</td>
<td>1 ECHo machine</td>
</tr>
<tr>
<td><strong>Screen daily in 5–6 h with specified resources</strong></td>
<td>100</td>
</tr>
</tbody>
</table>

ECHO indicates echocardiogram; and tech, technicians.
field. Improvement of the use of the H&P will only advance screening that adds an ECG to that process. The 2 sides of this debate should be working together and reframe this debate to reach their common goal of decreasing death in the young.14

We should perform ECG screening on all neonates and children in a large-scale scientific study to determine the best methodology to identify those at risk for SCD. The downstream effects of all screening for SCD conditions should be carefully investigated and adverse effects prevented. Only with that type of concerted effort will we have sufficient data to determine the best ways to screen, and on whom, by using best practices. What should be done does not mean it can be mandated at this time or that all the resources are currently available, but these recommendations should be considered from the same perspective that has driven major discoveries or solutions in other aspects of medicine and society.

Disclosures

None.

References


Response to Vetter

Richard A. Friedman, MD, MBA

In rebutting the argument in favor of ECG screening of all newborns, children, and teenagers, I find the common ground being the argument of whether we should embark on a massive screening program using the ECG in addition to the history and physical examination regardless of subgroup bias (ie, athletes).

- As mentioned, because the prevalence is so low, it does not matter whether the sensitivity is 100% and the specificity is 99%. Thus, the issue of new criteria for ECG diagnosis is a moot point.
- Cost-effectiveness, in terms of quality-adjusted life-years and life-years saved, does not substitute for the total cost of the screening. Screening just once will cost in the billions of dollars. Screening 3 times is even more ludicrous.
- Resource issues are grossly underestimated. Most pediatric ultrasonographers will attest to the fact that a new study will take no less than 30, and usually 45 minutes, to perform and interpret. A screening echo will not alleviate the diagnostic burden nor the legal liability of a missed diagnosis.
- Use of Italian data sets with discordant prevalence in comparison with the United States will result in a false sense of cost-effectiveness in the United States.

Although we always hope to save everyone we treat, we know this will never be the case. Moreover, the harm we do to those who are true positive, but who will never experience a sudden cardiac death, cannot be ignored. As a matter of public policy, we must not focus our ever increasingly scarce dollars and workforce to a mass-screening program.
Electrocardiographic Screening of All Infants, Children, and Teenagers Should Be Performed
Victoria L. Vetter

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