# Feasibility and findings of large-scale electrocardiographic screening in young adults: Data from 32,561 subjects

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**BACKGROUND** Large-scale electrocardiographic (ECG) screening of young athletes has been shown to reduce the incidence of sudden cardiac death in Italy. Debate exists regarding the feasibility and benefits of such a program in the United States.

**OBJECTIVE** The purpose of this study was to describe implementation and results of a large-scale high school ECG screening program (Young Hearts for Life [YH4L]) developed in the Chicago area.

**METHODS** A retrospective cohort study of 32,561 high school students from 38 ECG screenings was performed between September 2006 and May 2009. Screenings were performed by the YH4L program, which consisted of a core group of administrators, cardiologists, and community volunteers who underwent specialized training and quality review. The rates of abnormal ECGs requiring further evaluation and unacceptable ECGs due to poor quality were determined.

**RESULTS** Of the 32,561 students screened, 817 (2.5%) had abnormal ECGs requiring further evaluation. The majority of abnormal ECGs occurred in males (66%). Only 0.81% of ECGs were determined to be technically inadequate, requiring repeat ECGs on the same day of the screening. The prevalence of left ventricular hypertrophy and abnormal ST-T wave changes was lower in our study than in the rates reported in an Italian registry, possibly due to the lower frequency of men and highly trained athletes in our study.

**CONCLUSION** Large-scale ECG screening of U.S. high school students is feasible and identifies ECGs requiring further evaluation in 2.5% of individuals. These findings have implications for implementing screening and preventing sudden cardiac death in U.S. youth.

**KEYWORDS** Athlete; Electrocardiogram; Hypertrophic cardiomyopathy; Long QT syndrome; Screening; Sudden cardiac death

**ABBREVIATIONS** **ECG** = electrocardiogram; **LBB** = left bundle branch block; **LVH** = left ventricular hypertrophy; **SCD** = sudden cardiac death; **U.S.** = United States; **YH4L** = Young Hearts for Life

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## Introduction

Sudden cardiac death (SCD) in young adults (<35 years) is an emotionally staggering event, not only for the victim's family but also for the community. It likely is responsible for more than 2,500 deaths per year in the United States. Although the precise incidence in the United States is not known, it ranges between 0.6 and 13 deaths per 100,000.[1–4]

SCD in young adults is caused by multiple conditions, including hypertrophic cardiomyopathy, long QT syndrome, Brugada syndrome, arrhythmogenic right ventricular dysplasia, and Wolff-Parkinson-White syndrome.[5,6] Hypertrophic cardiomyopathy is the most common cause of SCD in this age group, accounting for approximately one third of cases.[7] The electrocardiogram (ECG) is abnormal in at least 90% of patients with hypertrophic cardiomyopathy.[8] Some, but not all, of the other conditions, such as anomalous coronary arteries, also can be detected by ECG.[9–11]

In Italy, screening young athletes with an ECG has proven effective in decreasing the annual rate of SCD.[12] ECG screening in the United States is hotly debated.[13–15] Those opposed question the feasibility of coordinating a large-scale ECG screening program. Also of concern has been the possibility of a high frequency of abnormal ECG findings, which prior reports have estimated to be as high as 10% to 40% in this population.[13,16,17] It is believed that the health care system could not support or finance the subsequent medical evaluations required for such a large number of individuals with abnormal ECGs.

In the present study, we describe an efficient method for mass ECG screening in high school students that results in high-quality ECG data, and we report the rate and distribution of abnormal ECG findings specific for high-risk cardiac conditions.

## Methods

### The Young Hearts for Life screening program

To address the problem of SCD in our community, the Young Hearts for Life (YH4L) cardiac screening program was initiated in 2006 under the sponsorship of the Midwest Heart Foundation. The YH4L model provides voluntary, mass ECG screening through cooperation with local high schools. Screening is offered to all physically active students during regular school hours and is not limited to athletes. The workforce necessary to perform the large number of ECGs is obtained by recruiting community volunteers, usually parents, and training

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them to perform ECGs. Training includes a 90-minute program that consists of a standardized didactic presentation followed by hands-on training with ECG machines and volunteer subjects. Competent performance of the 12-lead ECG procedure is validated by experienced clinical instructors. During the screenings, community volunteers are supervised by experienced nursing and technical personnel, and ECG quality is closely monitored. Approximately 20 ECG testing stations were available for each screening. ECGs were interpreted by on-site cardiologists during the testing day. Two to three cardiologists were on-site for ECG analysis and calculation of QT intervals. Using this model, more than 1,200 ECGs can be completed per day at each school. After compiling the cardiologist interpretations, normal results were communicated to the students' parents via letter or e-mail. The parents of students with abnormal ECG findings were telephoned by clinically trained personnel to discuss the interpretation and address questions they may have regarding further evaluation. Follow-up testing and consultation were conducted under the guidance of the students' primary care physicians.

## Study population

The study population consisted of consecutive students in 38 screenings at 24 high schools in the northern and western suburbs of Chicago between September 2006 and May 2009. All students, not just those participating in sports, were eligible for the screenings. Students were not charged a fee for participating in the screenings. Informed consent was obtained from parents prior to screening. Participation at each high school averaged 56% (range 18%–85%). Of note, in the state of Illinois it is customary for students to undergo a history and physical by their primary physician in concordance with American Heart Association guidelines.

## Electrocardiography

Standard 12-lead ECGs were performed with students in the supine position using portable ECG machines (list of equipment available from authors). Tracings were performed at 25 mm/s paper speed and 10 mm/mV gain. Low-pass filtering was set at 150 mHz. ECG quality assurance during the screening included (1) volunteer training as described earlier, (2) cardiologist supervision, (3) validation of waveform quality by experienced clinical personnel, (4) interpretation on-site by a board certified cardiologist, and (5) performance of repeat ECGs when necessary.

## Interpretation of ECGs

To enhance and ensure consistency, interpretation of ECGs was limited to six cardiologists experienced in the interpretation of adolescent ECGs and possessing knowledge of the ECG changes that occur in conditions associated with SCD. ECGs of uncertain clinical significance were reviewed by a panel of cardiologists, electrophysiologists, and pediatric cardiologists before a final interpretation was made.

ECGs with findings considered physiologic for this age group, such as isolated premature atrial contractions, incomplete right bundle branch block, early repolarization, mild bradycardia (>40 bpm, <60 bpm), and low atrial rhythms, were designated "within acceptable limits." Infrequent premature ventricular contractions (<3 per ECG rhythm strip) were considered "within normal limits" for this study, although we acknowledge the limitation that this may be an important finding in symptomatic individuals.

**Table 1** Criteria for abnormal screening ECGs requiring further evaluation

| Criteria for abnormal screening ECGs | |
|---|---|
| Rate <40 bpm, >125 bpm | Premature ventricular contractions ≥3 per 6-second tracing |
| QRS axis >120° (right-axis deviation) | Ventricular couplets/triplets |
| QRS axis >−30° (left-axis deviation) | Any supraventricular tachycardia |
| Right atrial enlargement, left atrial enlargement | ST-T wave abnormality in ≥2 leads* |
| QRS >120 ms (right bundle branch block, left bundle branch block, or interventricular conduction delay) | Abnormal Q wave (>0.04 second or >3 mm deep in ≥2 leads) |
| First-degree AV block >200 ms | QTc >460 ms |
| Second- or third-degree AV block | QS pattern in ≥2 precordial leads |
| "Brugada pattern" in lead $V_1$ | Modified left ventricular hypertrophy criteria† |
| Wolff-Parkinson-White syndrome | Poor R wave progression |

Criteria modified from Corrado et al.[12]

*ST-T wave abnormality included primarily inverted T waves but also >2-mm ST depression. Isolated T-wave inversion in lead aVR or lead $V_1$ was not considered abnormal.

†Modified left ventricular hypertrophy criteria include increased precordial voltage (>3 mV) plus increased limb lead voltage as determined by the standards of Davignon et al[22] or increased precordial lead voltage (>3 mV) accompanied by ST-T wave abnormalities, prominent q waves, extreme left-axis deviation (>−30°), or findings of left atrial enlargement.

Circumstances that required repeat ECGs with modifications were as follows:

1. *Baseline prolonged PR interval.* Repeat ECG was performed after hyperventilation. If the PR interval normalized, the ECG was designated as "within acceptable limits."
2. *Abnormal T-wave inversion in leads $V_2$–$V_4$.* ECG lead position was rechecked and repeated at 50 mm/s paper speed to detect epsilon waves.[18]
3. *Type III Brugada pattern in leads $V_1$ or $V_2$.* ECG was repeated with leads $V_1$ and $V_2$ placed in the third or second intercostal space ("Brugada leads").
4. *High resting heart rate due to anxiety.* ECG was repeated after the student laid supine in a quiet calm setting.

Abnormal ECGs were established by a modification of the criteria described by Corrado et al[12] to identify individuals at risk for SCD (Table 1).

## Diagnosis of left ventricular hypertrophy

ECG diagnosis of left ventricular hypertrophy (LVH) is challenging in this age group.[19] Due to many factors, including thin body habitus, precordial lead voltage often is increased. Isolated increased precordial lead voltage by itself is not a specific criterion for diagnosis of LVH in this age group.[17,20,21] Therefore, we considered an ECG diagnosis of LVH if the following criteria were met:

1. Increased precordial voltage (>3 mV) plus increased limb lead voltage as determined by the standards of Davignon et al[22] or
2. Increased precordial lead voltage (>3 mV) accompanied by ST-T wave abnormalities, prominent q waves, extreme left-axis deviation (>–30°), or findings of left atrial enlargement (p-wave duration >100 ms or p wave in lead $V_1$ >40 ms and depth >0.1 mV).

### Measurement of QT interval

Computer determination of QT interval has been consistently shown to be inaccurate.[23] All QT intervals were visually assessed, and borderline QT intervals were measured manually in lead II or lead $V_5$ using the method of tangent to determine the end of the T wave.[24] U waves were included in the calculation if they were greater than 50% of the T wave in these leads. The corrected QT (QTc) interval was calculated using the Bazett formula.

### Statistical analysis

ECG abnormalities were categorized based on conditions associated with SCD. The distribution of abnormal ECGs based on age and gender and the rate of abnormal ECGs in each school with the rate of abnormal ECGs for all schools were compared. The rate of specific ECG abnormalities in our study was compared with the rate of the same abnormalities in the large Italian registry.[25] Means were compared using the two-sided t-test and proportions by the Chi-squared test. $P$ <.05 was considered significant.

## Results

### Study group

A total of 32,561 high school students (51% male) participated in the ECG screening program during the study dates. Mean age was 16 years (range 14–19 years). The average number of students screened per school was 880 (range 111–2,518). The proportion of students participating in organized sports was 30%. Less than 3% of students were sedentary, which as defined as less than 2 hours of organized physical activity per week.[20] Ethnicities of the last 13,281 consecutive students are shown in Figure 1.

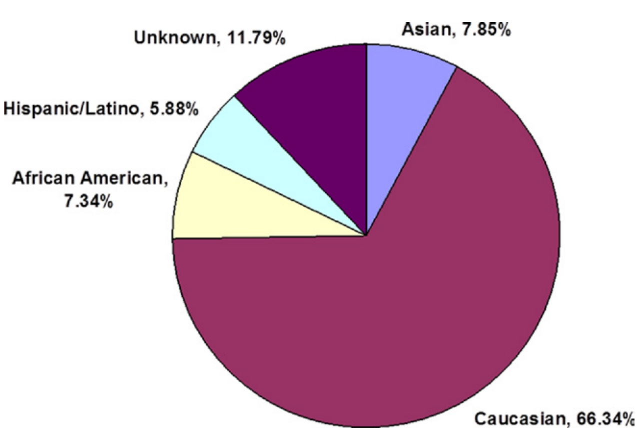


**Figure 1** Ethnic distribution of 13,281 consecutive students. Unknown = ethnicity was reported as unknown by parents and students.

**Table 2** Overall distribution of ECG findings

| ECG finding | No. | Percent of total abnormal ECGs (n = 817) | Percent of total ECGs (n = 32,561) |
|---|---|---|---|
| Left-axis deviation | 110 | 13.5% | 0.34% |
| Right-axis deviation | 41 | 5.0% | 0.13% |
| Prolonged QT | 100 | 12.2% | 0.31% |
| ST-T wave abnormality | 139 | 17.0% | 0.43% |
| Left ventricular hypertrophy | 141 | 17.2% | 0.43% |
| Right ventricular hypertrophy | 59 | 7.2% | 0.18% |
| Left atrial enlargement | 5 | 0.6% | 0.02% |
| Right atrial enlargement | 3 | 0.4% | 0.01% |
| Right bundle branch block | 51 | 6.2% | 0.16% |
| Interventricular conduction delay (QRS >120 ms) | 25 | 3.1% | 0.08% |
| Left bundle branch block | 0 | 0% | 0% |
| Poor R-wave progression | 9 | 1.1% | 0.03% |
| Abnormal Q waves | 7 | 0.8% | 0.02% |
| Wolff-Parkinson-White syndrome | 42 | 5.1% | 0.13% |
| Premature ventricular contractions | 17 | 2.1% | 0.05% |
| Premature atrial contractions | 2 | 0.2% | 0.01% |
| Atrial fibrillation | 2 | 0.2% | 0.01% |
| Sinus tachycardia | 7 | 0.9% | 0.02% |
| Sinus bradycardia | 2 | 0.2% | 0.01% |
| First-degree AV block | 12 | 1.5% | 0.04% |
| Second-degree AV block | 4 | 0.5% | 0.01% |
| Other* | 38 | 5.6% | 0.14% |
| Total | 817 | 100% | 2.51% |

*Other includes atrial paced rhythm (n = 1), ectopic atrial tachyarrhythmia (n = 4), dextrocardia (n = 3), atypical right bundle branch block (n = 4), northwest QRS axis (n = 9), and short QT interval (n = 2).

### ECG quality assurance

The quality tracking system identified 0.81% of screening ECGs to be technically unacceptable, and these ECGs were repeated the same day. The primary reasons for unacceptable ECGs were limb lead reversal, inaccurate precordial lead placement, and excessive baseline artifact.

### ECG findings

The majority of ECG findings were either normal or within acceptable limits. Of the 32,561 screened students, 2.5% had abnormal ECGs. The overall distributions of these abnormalities are listed in Table 2. Criteria for LVH were present in 0.43% of ECGs. Excluding those ECGs with only voltage criteria, LVH was present in 0.11% of all ECGs.

No relationship was seen between age and any ECG abnormality ($P$ >.05 for all associations). The distributions of ECG abnormalities according to gender are listed in Table 3. Approximately 66% of all abnormal ECGs were in males. Significant gender differences were seen in the prevalence of LVH by voltage, LVH with other abnormalities, ST-T wave abnormalities, prolonged QT interval, and left-axis deviation. No difference was seen in the rate of abnormal ECGs among the 24 schools included in the study (range 1.1%–4.8%, $P$ >.05).

## Discussion

This is the largest reported ECG screening study in the United States. The study demonstrates the feasibility, high quality, and large-scale application of ECG screening for young adults in the United States. In addition, it identifies the expected rate of

**Table 3** Distribution of most common ECG abnormalities by gender

| ECG abnormality | Male (%) | Female (%) | *P* value |
|---|---|---|---|
| Left ventricular hypertrophy | 132 (24.9%) | 9 (4.1%) | <.0001 |
| Left-axis deviation | 99 (19%) | 11 (5.0%) | <.0001 |
| ST-T wave abnormality | 86 (16%) | 53 (2.4%) | .005 |
| Prolonged QT | 27 (5.1%) | 73 (3.3%) | <.0001 |
| Right-axis deviation | 32 (6.1%) | 9 (4.1%) | .0003 |
| Right ventricular hypertrophy | 47 (8.9%) | 12 (5.4%) | <.0001 |
| Right bundle branch block | 37 (7.0%) | 14 (6.3%) | .0013 |
| Interventricular conduction delay | 21 (4.0%) | 4 (1.8%) | .0007 |
| Poor R-wave progression | 3 (0.57%) | 6 (2.7%) | .3170 |
| Wolff-Parkinson-White syndrome | 27 (5.1%) | 15 (6.8%) | .0640 |
| First-degree AV block | 3 (0.57%) | 9 (4.1%) | .0833 |
| Premature ventricular contractions | 10 (1.9%) | 7 (3.2%) | .4666 |
| Atrial fibrillation | 2 (0.38%) | 0 (0%) | .1573 |
| Total abnormal ECG | 526 | 222 | |

abnormal ECGs (2.5%) in this population, which helps anticipate the resources required for subsequent medical evaluations of screened communities.

As described, the YH4L model allows for efficient, high-quality, mass ECG screening at low cost by partnering with local area high schools and trained community volunteers. High-quality ECG data were achieved by a combination of prescreening standardized training sessions and on-site cardiologists. The average cost per ECG was $8.67 using the YH4L model.[26] In our study, physician readings were performed on a volunteer basis. Costs for physician ECG interpretation can vary widely. For example, in 2009 the Centers for Medicare & Medicaid Services reimbursement for the physician component of ECG interpretation was $9.52 (http://www.wpsmedicare.com/part_b/fees/prior_pricing/fees_2009.shtml). Another method is to pay physicians an hourly rate to read ECGs on-site at screenings. The physician cost then would be influenced by the number of ECGs read per hour. One program estimates this cost to be $4.50 per ECG (Personal Communication, March 17, 2011, Mary Beth Schewitz, Max Schewitz Foundation, Lake Forest, IL, USA). Using these estimates as a range for physician interpretation costs, the total cost per ECG would range from $13.17 to $18.19.

SCD in young adults is of great concern to the community. There is considerable disagreement on the proper strategy to identify healthy youth at risk for SCD. One of the main arguments against ECG screening is that the rate of abnormal ECGs will be unmanageably high; one prior study reported a frequency of 40%.[17] It is feared that this could drain the resources of the medical community and not meet reasonable cost-effectiveness criteria demanded of a screening program. This one concern has been a major deterrent to the adoption of widespread ECG screening.

Prior studies, however, were not representative of the population requiring screening for three reasons. First, the studies were confined to elite athletes, who represent a small proportion of the total population of youths in the community at risk for SCD. Second, the higher prevalence of abnormal ECG findings in elite athletes is well recognized.[17,27] Third, prior studies defined abnormal ECGs by criteria that included physiologic changes that are not associated with SCD. Our study addresses these issues by shifting the focus from identifying all ECG abnormalities to identifying only ECGs with findings suggestive of disorders associated with SCD. Using this approach, our study demonstrates a prevalence of clinically significant ECG findings of only 2.5%. This represents an acceptable "abnormal" rate for the medical community, resources for evaluations, and the psychosocial impact for individuals and their families with "abnormal" findings.

Pelliccia et al[25] reported ECG results for 32,652 unselected young athletes in Italy, where ECG screening is mandatory for athletes but not for all young adults. A comparison of our findings with that large Italian registry provides interesting insights (Table 4). The major differences were in the rates of LVH, ST-T wave abnormalities, bundle branch block or intraventricular conduction delay, and prolonged QT interval.

The greater frequency of LVH and abnormal ST-T wave abnormalities in the Italian registry may be due to a greater percentage of males and elite athletes in their population. The finding of LVH in females should be viewed with more caution compared to males given that it is a relatively infrequent finding. The rate of ECGs with a prolonged QT was greater in our study and likely is due to a greater percentage of females in our study (49% YH4L vs 20% Pelliccia et al). This occurred despite our use of more restrictive criteria for a prolonged QT interval (QTc ≥460 ms in both genders compared to ≥450 ms in males and ≥460 ms in females in the Italian study). Basavarajaiah et al[28] reported a 0.4% prevalence of a prolonged QT interval in 2,000 elite British athletes using a threshold of 460 ms, a frequency more consistent with our results. Another factor may be the method for determining QT intervals and potential for interobserver varability.[29] In our study, the QT interval was agreed upon by a consensus of several experienced cardiologists in order to improve the accuracy of this measurement.

## Study limitations

Our study results are based primarily on a Caucasian cohort and may not reflect the findings in other ethnicities. This study was not designed to determine the prevalence of cardiac disorders but rather the feasibility and findings in conducting large-scale ECG screening in physically active young adults.

**Table 4** Comparison of YH4L ECG findings with the Italian National Registry[25]

| ECG abnormality | Italian registry (n = 32,652) (%) | YH4L program (n = 32,561) (%) | *P* value |
|---|---|---|---|
| Left ventricular hypertrophy | 247 (0.8%) | 141 (0.43%) | <.0001 |
| Wolff-Parkinson-White syndrome | 42 (0.1%) | 42 (0.13%) | .99 |
| Prolonged QT | 1 (0.003%) | 100 (0.31%) | <.0001 |
| Bundle branch block or interventricular conduction delay | 370 (1.1%) | 76 (0.23%) | <.0001 |
| Left-axis deviation | 162 (0.5%) | 110 (0.34%) | .002 |
| ST-T wave abnormality | 751 (2.3%)* | 139 (0.43%)† | <.0001 |

Data for the Italian National Registry were obtained from Corrado et al.[12]
YH4L = Young Hearts 4 Life.
*Negative T waves.
†Included all ST-T wave abnormalities but were predominantly negative T waves.

Thus, our study could not determine the number of "false-positive" ECGs because subsequent clinical evaluations of students with abnormal ECGs were performed by individuals' personal physicians. We currently are obtaining follow-up evaluations for these students to determine the false-positive rate, the appropriateness and cost of subsequent evaluations, and the final diagnoses.

The American Heart Association estimates the combined disease prevalence of all cardiovascular disorders that predispose young athletes to SCD is 0.3%.[16] Multiple prior studies using ECG screening have demonstrated that the prevalence of potentially lethal cardiovascular diseases in athletes ranges between 0.2% and 0.7%.[12,30–33] It is likely that follow-up evaluations for individuals in this study with a positive screen would yield a similar proportion of identified cardiovascular disease.

## Conclusion

The present study demonstrates the feasibility of performing high-quality ECG screening at low cost in large populations of U.S. youth and identifies a relatively low prevalence of abnormal ECGs (2.5%) requiring subsequent medical evaluation when they are interpreted by experienced cardiologists using contemporary criteria. Our findings have important implications for the implementation of ECG screening and the potential to reduce the rate of SCD in U.S. youth.

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