Addition of the Electrocardiogram to the Preparticipation Examination of College Athletes

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Objective: Although the use of standardized cardiovascular (CV) system–focused history and physical examination is recommended for the preparticipation examination (PPE) of athletes, the addition of the electrocardiogram (ECG) has been controversial. Because the impact of ECG screening on college athletes has rarely been reported, we analyzed the findings of adding the ECG to the PPE of Stanford athletes.

Design: For the past 15 years, the Stanford Sports Medicine program has mandated a PPE questionnaire and physical examination by Stanford physicians for participation in intercollegiate athletics. In 2007, computerized ECGs with digital measurements were recorded on athletes and entered into a database.

Setting: Although the use of standardized CV-focused history and physical examination are recommended for the PPE of athletes, the addition of the ECG has been controversial. Because the feasibility and outcomes of ECG screening on college athletes have rarely been reported, we present findings derived from the addition of the ECG to the PPE of Stanford athletes. For the past 15 years, the Stanford Sports Medicine program has mandated a PPE questionnaire and physical examination by Stanford physicians for participation in intercollegiate athletics. In 2007, computerized ECGs with digital measurements were recorded on athletes and entered into a database.

Main Outcome Measures: Six hundred fifty-eight recordings were obtained (54% men, 10% African-American, mean age 20 years) representing 24 sports. Although 68% of the women had normal ECGs, only 38% of the men did so. Incomplete right bundle branch block (RBBB) (13%), right axis deviation (RAD) (10%), and atrial abnormalities (3%) were the 3 most common minor abnormalities. Sokolow-Lyon criteria for left ventricular hypertrophy (LVH) were found in 49%; however, only 27% had a Romhilt-Estes score of ≥4. T-wave inversion in V2 to V3 occurred in 7%, and only 5 men had abnormal Q-waves. Sixty-three athletes (10%) were judged to have distinctly abnormal ECG findings possibly associated with conditions including hypertrophic cardiomyopathy or arrhythmogenic right ventricular dysplasia/cardiomyopathy. These athletes were offered further testing but this was not mandated according to the research protocol.

Results: Six hundred fifty-three recordings were obtained (54% men, 7% African American, mean age 20 years), representing 24 sports. Although 68% of the women had normal ECGs, only 38% of the men did so. Incomplete RBBB (13%), RAD (10%), and atrial abnormalities (3%) were the 3 most common minor abnormalities. Sokolow-Lyon criteria for LVH were found in 49%; however, only 27% had a Romhilt-Estes score of ≥4. T-wave inversion in V2 to V3 occurred in 7% and only 5 men had abnormal Q-waves. Sixty-five athletes (10%) were judged to have distinctly abnormal ECG findings suggestive of arrhythmogenic right ventricular dysplasia, hypertrophic cardiomyopathy, and/or biventricular hypertrophy. These athletes will be submitted to further testing.

Conclusions: Mass ECG screening is achievable within the collegiate setting by using volunteers when the appropriate equipment is available. However, the rate of secondary testing suggests the need for an evaluation of cost-effectiveness for mass screening and the development of new athlete-specific ECG interpretation algorithms.

Key Words: college athletes, sudden death, preparticipation examination, ECG screening

(*Clin J Sport Med* 2010;20:98–105)

INTRODUCTION

Sudden cardiac deaths (SCDs) in athletes raise concerns and debate regarding the efficacy of preparticipation cardiovascular (CV) screening. Currently, all experts agree that the preparticipation examination (PPE) of competitive athletes should include a CV-oriented history and physical examination.[1,2] However, the addition of the resting 12-lead electrocardiogram (ECG) to the PPE remains controversial.

Based on the recognition that an abnormal ECG may identify cardiomyopathies responsible for athletic deaths, the European Society of Cardiology (ESC) Consensus Document

Submitted for publication August 5, 2009; accepted January 13, 2010.
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recommended the inclusion of a rest ECG to the PPE.[2] This proposal largely derives from the long-standing experience in Italy, where a mandated screening program has been implemented since 1982. In a recent observational study, Corrado et al[3] reported a reduction in SCDs in athletes by almost 90% after the inclusion of ECGs in PPE. This marked reduction was partly attributable to the identification of cardiomyopathies such as arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C) and exclusion of these athletes from competitive sports.

However, the normal physiologic changes occurring in athletic hearts are not completely understood. In addition, the ECG is known to exhibit a low positive predictive value in low prevalence populations, leading to the suggestion that the ECG has low specificity in athletes when using standard ECG criteria.[3] Moreover, in previously published studies, broad criteria for interpretation have been used, and recommended, without considering, age, gender, sports discipline, and ethnicity.[4,5] Partly for these reasons, the American Heart Association (AHA) has not supported the addition of the ECG to the PPE of American athletes.[1]

Nonetheless, the ECG may still detect subtle and significantly abnormal findings, including preclinical disease not detected by echocardiogram.[6] With better understanding of the prevalence of each potentially abnormal finding in athletes, it may be possible to develop evidence-based criteria of ECG interpretation with higher sensitivity and specificity for identifying potentially lethal conditions. Because the impact of ECG screening on college athletes has rarely been reported, we aimed to describe the findings of adding the ECG to the PPE of Stanford athletes and to create a digital database to improve the criteria for the "normal" ECG in athletes.

METHODS

Study Population

Our target population was undergraduate Stanford University students competing in intercollegiate sports. To compete, all athletes must complete a Web-based PPE questionnaire regarding personal and family medical, surgical, and CV history. They all undergo a CV and orthopedic-focused physical examination by Stanford physicians who have the results of the questionnaires available to them. At the time of physical examination, the athletes were offered to participate in the study, consisting of a rest ECG and collection of historical information. The study protocol was approved by the Stanford Hospital and Clinics Institutional Review Board. Written informed consent was obtained from all participating athletes. More than 95% of athletes (a total of 658 subjects) agreed to participate. Athletes who did not have ECGs were only those scheduled for PPE outside the time when ECG was offered. All were participants in sports with low CV impact such as fencing and golf.

TABLE 1. Baseline Characteristics

Characteristics	Entire Population n = 658	Men n = 358 (54)	Women n = 300 (46)	*P* Value
Age, y	20	20	19 (19–20)	0.001
BMI, kg/m^2	23.2 (22.9–23.5)	24.3 (23.8–24.5)	22.1 (21.8–22.5)	<0.001
Ethnicity, No. (%)				0.01
White	484 (74)	253 (71)	231 (77)	
African American	67 (10)	48 (13)	19 (6)	
Hispanic	43 (6)	26 (7)	17 (6)	
Asian*	64 (10)	31 (9)	33 (11)	
Sports, No. (%)				<0.001
Basketball	18 (3)	9 (3)	9 (3)	
Football	64 (11)	64 (19)	0	
Water sports†	102 (17)	54 (16)	48 (17.3)	
Crew	68 (11)	30 (9)	38 (14)	
Sailing	13 (2)	4 (1)	9 (3)	
Field sports‡	138 (23)	24 (19)	74 (27)	
Racquet sports§	28 (5)	7 (2)	21 (8)	
Floor sports¶	64 (11)	45 (13)	19 (7)	
Court sports‖	39 (7)	23 (7)	16 (6)	
Track and field‡	62 (10)	26 (8)	36 (13)	
Golf	16 (3)	9 (3)	7 (4)	

Number in percentage or median (with 95% confidence interval).
*Pacific Islanders.
†Swimming, water polo, synchronized swimming, and diving.
‡Lacrosse, field hockey, baseball, softball, and soccer.
§Squash and tennis.
¶Gymnastics and wrestling.
‖Volleyball and fencing.
#Track and field and cross-country.
BMI, body mass index.

Athletes were engaged in 24 different sporting disciplines. After reasonable groupings of similarity, 11 categories were formed (Table 1): football, basketball, crew, sailing, golf, water sports (including swimming, water polo, synchronized swimming, and diving), field sports (including lacrosse, field hockey, baseball, softball, and soccer), racquet sports (including squash and tennis), floor sports (including gymnastics and wrestling), court sports (including volleyball and fencing), and track/field (including track/field and cross-country).

ECG Analysis

Volunteers recorded ECG using Schiller ECG machines. Digital recordings were entered into a database (SEMA; Schiller AG, Baer, Switzerland). The 658 ECGs were analyzed by cardiologists (V-V.L., V.F., M.P., E.A.A.) who entered the visual interpretation and selected visual measurements into a custom database (Studytrax; Sciencetrax, Jacksonville, Florida) using a standardized form. After data entry, all ECGs were reviewed by two experienced investigators (V-V.L. and V.F.F.). For the analysis, the findings were divided into 3 categories: minor abnormalities, major abnormalities, and abnormalities suggestive of a cardiomyopathy. The presence of ≥1 finding, except early repolarization, was considered abnormal. Minor abnormalities included early repolarization, axis deviation (QRS axis ≤ −30° or ≥ 120°), atrial abnormality (*left atrium*: negative portion of the P wave in lead V1 ≥ 100 milliseconds and ≥0.04 seconds in duration V1 and *right atrium*: peaked P wave in leads II and III or V1 ≥ 0.25 mV in amplitude AVF),[7] low voltage, and abnormal QRS conduction except left bundle branch block (LBBB). Major abnormalities included LBBB; abnormal Q-waves (≥40 milliseconds or ≥25% of the height of the ensuing R wave or QS pattern in ≥ 2 leads); right ventricular hypertrophy (RVH)[8]; left ventricular hypertrophy (LVH) using the Sokolow-Lyon criteria,[9] and the Romhilt-Estes point score system (a score of ≥4 suggests possible LVH),[10] and the ESC voltage criteria[2]); T-wave inversion or ST depression in ≥ 2 leads except in V1-V2; supraventricular arrhythmia; premature ventricular contraction (PVC); and ventricular arrhythmia. The third category of findings consisted of patterns suggestive of diseases associated with SCD including long QT syndrome (QTc > 440 milliseconds in men and > 460 milliseconds in women),[2] the type 1 pattern Brugada pattern,[11] Wolff-Parkinson-White (WPW) pattern,[12] and the ARVD/C pattern. For the last, we considered 2 of the major ECG criteria recommended by the ESC, that is, presence of epsilon wave and/or presence of localized QRS >110 milliseconds in V1-V3 in the absence of right bundle branch block (RBBB).[2] We also considered any prolonged S wave upstroke in V1-V3 of ≥55 milliseconds because this criterion has been associated with disease severity and induction of ventricular tachycardia in ARVD/C.[13] As with other measurements such as P wave amplitude and duration, S wave upstroke was first estimated visually and confirmed with computer caliper measurements.

For comparisons with published literature, ECG findings were also evaluated according to the commonly adopted ESC Consensus Document clinical criteria[2] and Pelliccia ECG pattern classification.[4]

This study was designed as an observational study of ECG findings in a collegiate setting and not to validate the role of the ECG as a screening tool for CV disorders. Only athletes judged to have significant abnormalities by the senior investigator (V.F.F.) were offered further testing, which included echocardiography and/or cardiac magnetic resonance imaging (MRI). The Stanford-adapted "distinctly abnormal" findings were abnormal Q wave, ST depression, or T-wave inversion in ≥2 leads; LVH or biventricular hypertrophy with strain; RBBB; right atrial abnormality[14]; any ECG pattern suggestive of diseases associated with SCD; low voltage; and the presence of multiple abnormalities (>2 positive ECG findings). These criteria were empirically developed and derived from the senior author's (V.F.F) experience with the screening of US Air Force air crewmen, college athletes, academy attendees, and astronauts. Additional workup however was elective.

Statistical Analysis

Differences in clinical and exercise variables were compared using χ^2 tests, Mann-Whitney U test and unpaired *t*-test when appropriate. Statistical analyses were performed using NCSS (NCSS Inc, Kayesville, Utah). A 2-sided *P* value less than 0.05 was considered statistically significant.

RESULTS

Health Questionnaire and Physical Examination

The median age for the entire population was 20 years, and 54% were men (Table 1). The median body mass index (BMI) was 24.3 kg/m^2 (95% confidence interval [CI], 23.8-24.5 kg/m^2) for male athletes and was significantly lower for women (22.1 kg/m^2; 95% CI, 21.8-22.5 kg/m^2; $P = 0.001$). The population was mainly white for both sexes. African Americans constituted 10% of the population, and 10% were Asian/Pacific Islanders (Table 1).

One hundred twenty (120) athletes (18%) reported at least 1 positive finding in the family history questionnaire. Coronary artery disease (CAD) was the most frequent disease reported, followed by 8 cases of valvular heart diseases and 8 cases of arrhythmias. Six reported a family history of sudden unexplained death. One female athlete reported a second-degree relative history of hypertrophic cardiomyopathy (HCM) and she was asymptomatic.

Seventy athletes (11%) reported at least 1 positive finding in their personal history questionnaire. There was no self-reported history of HCM, dilated cardiomyopathy, valvular diseases, and/or aneurysms. Thirty-one athletes (5%) reported experiencing chest pain either during or after physical activity. Syncope/near-syncope was reported by 30 athletes, with the majority of those events occurring during physical activity. Although 13 reported a history of heart murmur, only 4 athletes presented heart murmurs during physical examination. Three had subsequent normal echocardiograms, and 1 was diagnosed with a de novo patent ductus arteriosus.

In contrast to most Italian studies, only 5% had previously undergone any type of CV testing before participation in this study.

ECG Findings

Median heart rate (HR) was 59 beats per minute for the entire group. R wave and J-junction amplitudes (in anterior and lateral leads) were visually significantly greater in male athletes (Table 2).

Minor Abnormalities

Early repolarization, the most frequent minor abnormality, was seen in 38% of athletes (Table 2). One hundred fifty-six athletes (24%) presented at least 1 other minor abnormality. Incomplete right bundle branch block was seen in 13%, and right axis deviation (RAD) was seen in 10% of athletes. All 3 findings were significantly more common in men than in women. Atrial abnormalities were present in 3%, and only 1% had complete RBBB.

Major Abnormalities

Thirty-four percent (222 athletes) of our population presented at least 1 major abnormality. Male athletes presented more frequently major abnormalities than female athletes (47% vs 18%; $P < 0.001$). Left ventricular hypertrophy was the most frequent major abnormality and was seen in 49% of our population using the Sokolow-Lyon voltage criteria (Table 4). Using the Romhilt-Estes point score, its prevalence was lower (27%), and with the ESC Consensus Statement criteria, the prevalence was lowest (20%). Regardless of the criteria used, LVH was always more prevalent in men. T-wave inversion, the second most common major abnormality, was seen in 7% and was almost 4 times more frequent in women. Right ventricular hypertrophy was found by ECG in 2% and resting PVCs were noted in <1%, both without significant differences between genders. Abnormal Q waves were only seen in 5 male athletes ($P = 0.04$). We did not note any other rhythm disorders than junctional rhythm found in 1 female athlete. No ECG exhibited LBBB.

TABLE 2. ECG Findings

Characteristics	Entire Population n = 658	Men n = 358	Women n = 300	*P* Value
Rest HR (beats/min)	59 (58–60)	59 (57–60)	60 (58–61)	0.41
Minor absornmalities, No. (%)	156 (24)	97 (27)	59 (20)	0.03
Early repolarization	247 (38)	187 (53)	60 (20)	<0.001
Incomplete RBBB	5 (13)	55 (15)	30 (10)	0.04
RAD	64 (10)	43 (12)	21 (7)	0.03
Left axis deviation	6 (1)	3 (1)	3 (1)	0.83
Atrial abnormality	20 (3)	13 (4)	7 (2)	0.33
Complete RBBB	9 (1)	5 (1)	4 (1)	0.94
Low voltage	3 (1)	1 (<1)	2 (1)	0.46
Major absornmalities, No. (%)	222 (34)	169 (47)	53 (18)	<0.001
LVH (Sokolow-Lyon)	321 (49)	237 (66)	84 (28)	<0.001
LVH (Romhilt-Esles)	176 (27)	155 (43)	21 (7)	<0.001
LVH (ESC)	130 (20)	93 (26)	37 (12)	<0.001
R Amplitude LL, mm	14	15 ± 5	14 ± 4	<0.001
R Amplitude PcL, mm	20 (19–20)	22 ± 7	18 ± 6	<0.001
Lateral ST elevation, mm	0.5	1 (0.6–1.0)	0.2 (0.2–0.3)	<0.001
Anterior ST elevation, mm	1.5 (1.0–1.5)	2	1	<0.001
T-wave inversion	44 (7)	10 (3)	34 (11)	<0.001
Anterior	38 (6)	7 (2)	31 (10)	<0.001
Inferior	8 (1)	3 (1)	5 (2)	0.33
Lateral	6 (1)	1 (<1)	5 (2)	0.06
Abnormal Q waves	5 (1)	5 (1.4)	0	0.04
RVH	13 (2)	9 (3)	4 (1)	0.29
PVC	3 (1)	2 (1)	1 (<1)	0.67
ECG cardiomyopathy patterns, No. (%)				
ARVD/C	6 (1)	3 (<1)	3 (1)	0.54
WPW	2 (<1)	2 (<1)	0	0.9

Left bundle branch block (LBBB), long or short QTc patterns, and Brugada pattern were not seen in our cohort. Results are presented as number (%), mean ± SD or median (95% confidence interval).

ARVD/C, arhythmogenic right ventricular dysplasia/cardiomyopathy; ECG, electrocardiogram; ESC, European Society of Cardiology; HR, heart rate; LL, lateral limb; LVH, left ventricular hypertrophy; PcL, percordial limb; PVC, premature ventricular confractions; RAD, right axis deviation; RBBB, right bundle branch block; RVH, right ventricular hypertrophy; WPW, Wolff-Parkinson-White.

ECG Patterns Suggestive of Cardiac Diseases Associated With SCD

Eight athletes (<2%) had more than 1 abnormality potentially suggestive of underlying cardiomyopathy or channelopathy. Seven (1%) presented a slurred S wave in V1-V3 suggestive of an ARVD/C pattern, but no epsilon waves were seen. T-wave inversion in these leads in the absence of RBBB, a minor ESC ARVD/C criterion,[2] was seen in 6% and was 5 times more common in women. Two athletes presented a WPW pattern (0.3%); both were asymptomatic and allowed to participate in competitive sports.[16] Long or short QTc and Brugada patterns were not seen (Table 2).

Abnormal ECG by Ethnicity and Sports Discipline

The percentages of abnormal ECG were highest in football, track-field, and rowing (Figure 1; $P = 0.08$). Sailing and floor sports presented the lowest percentage of abnormal ECGs. There were no statistical differences among ethnic groups (Table 3; 49% of abnormal ECG in white, 51% in African Americans, 47% in Hispanic, and 47% in Asian/Pacific Islanders; $P = 0.24$).

With our criteria, 52% had a normal ECG (Table 4). Although only 38% of men had a normal ECG, 68% of women had a normal ECG ($P < 0.001$). Using the ESC Consensus Document criteria,[2] 35% would need further testing based on ECG findings alone. The ESC LVH criteria, seen in 130 athletes (20%), RAD seen in 10%, and T-wave inversions seen in 50 athletes (7%), were the most frequent ESC abnormal findings. Using the ECG classification described by Pelliccia et al,[4] 15% presented a distinctly abnormal ECG. A striking increase in R or S wave voltage (≥35 mm) in any lead, seen in 22 athletes, and RAD accounted for 13% of the distinctly abnormal findings. Regardless of the criteria considered, the prevalence of abnormal ECG was always significantly higher in men.

Using Stanford criteria for distinctly abnormal ECG (Table 5), 63 athletes (10%) were judged to have abnormalities that should be investigated. Further testing including echocardiography and/or cardiac MRI was offered but not required for sports participation. Presented in Figure 2 is an example of an ECG with multiple abnormalities in a female athlete whose MRI was normal.

Of the 63 athletes with abnormal ECGs, 15 men and 9 women (n = 24) accepted the offer of a follow-up cardiac MRI study. All women had a normal study. Of the male athletes, one had a septal thickness at the upper limit of normal (13 mm) and another had a borderline dilated left ventricle (LV) with an ejection fraction (EF) of 50%. Both presented with abnormal precordial R- or S-wave voltage on the ECG. Both were allowed to continue to compete and decided to do so after receiving a balanced explanation of the potential risk of doing so. The need for re-evaluation and self-reporting of any symptoms was stressed. Finally, a third male with RVH and T-wave abnormalities on the ECG initially declined further testing. He later presented with a symptomatic tachyarryhthmia, which led to the finding of hypertrabeculation and lower limits of normal EF. In addition, he manifested lower than expected exercise capacity. Because of this combination of findings, and the current uncertainty regarding the definition of noncompaction cardiomyopathy,[17] its overlap with HCM, and its sports-associated risk, a recommendation was made against continued participation in high-level competitive exercise.

TABLE 3. Percentage of Abnormal ECG by Ethnicity

Ethnicity	No. (%) $P = 0.96$
White	232 (48)
African American	20 (47)
Hispanic	34 (51)
Asian	30 (47)

ECG, electrocardiogram.

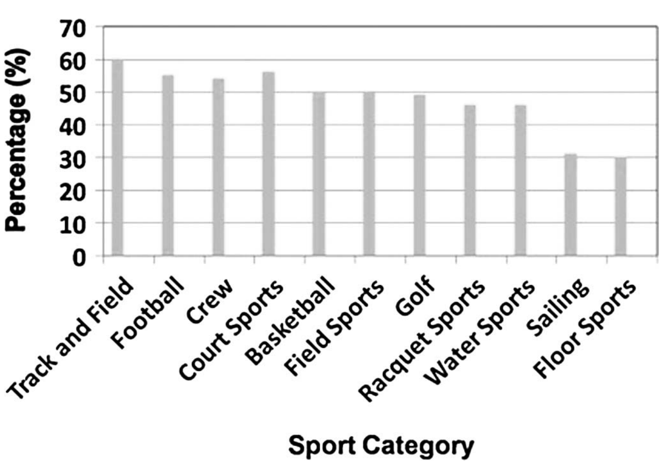

FIGURE 1. Percentage of abnormal electrocardiogram (ECG) by sport category. $P = 0.08$.

DISCUSSION

In a recent observational study that comprised 2 sequential screening periods, Corrado et al[3] reported

TABLE 4. Percentage of Normal and Abnormal ECG Summary

Characteristics, No. (%)	Entire Population n = 658	Men n = 358 (54)	Women n = 300 (46)	P Value
Normal ECG	342 (52)	137 (38)	205 (68)	<0.001
Normal ECG according to ESC	428 (65)	205 (57)	223 (74)	<0.001
Distinctly abnormal ECG*	101 (15)	73 (20)	28 (9)	<0.001
Stanford Distinctly Abnormal ECG	63 (10)	41 (12)	22 (7)	0.07

Results are presented as number (%).
*Adapted from Pelliccia et al.[15]
ESC, European Society of Cardiology.

TABLE 5. Stanford University Adapted Distinctly Abnormal Findings (n = 63)

Characteristics	No. (%)
Abnormal Q wave/T wave/ST segment	12 (19)
Left ventricular hypertrophy with strain	10 (16)
Biventricular hypertrophy with strain	9 (14)
RBBB	8 (13)
Multiple abnormalities	7 (11)
ARVD/C pattern	7 (11)
Right atrial abnormality	6 (10)
Low voltage	2 (3)
WPW pattern	2 (3)

Number presented in percentage (%).
ARVD/C, arrhythmogenic right ventricular dysplasia/cardiomyopathy; RBBB, right bundle branch block; WPW, Wolff-Parkinson-White.

a reduction in SCDs in athletes by almost 90% after the inclusion of ECG in PPE. This reduction is remarkable considering that a number of relatively more recently recognized pathological conditions, such as long and short QT syndromes and Brugada syndrome, were not considered routinely in the previously published studies.[18] Because as much as 30% of SCD can occur in macroscopically normal hearts,[19] one can assume that the impact of the addition of ECG to PPE on mortality has not been entirely assessed yet. However, if mass screening was to be instituted in the United States, the demographic and scholastic settings have to be identified and specific criteria for ECG interpretation developed due to the uncertainty surrounding the sensitivity and specificity of this test in this population.[1] Because 16% of exercise-related SCDs in the United States were identified in college students,[20] a better understanding of ECG findings in this particular population is therefore essential. We suspected that a highly trained student-athlete population, as found in previous studies, would have a relatively high rate of ECG abnormalities. In this study, we have clearly delineated the abnormalities found in both male and female college athletes.

Major abnormalities were found in more than a third of our population. The isolated finding of LVH mostly contributed to this high percentage. The high rate of LVH has also been previously observed in trained junior elite athletes.[21] Using the Romhilt-Estes point score, the prevalence of LVH was lower than using the Sokolow-Lyon voltage criterion. Romhilt-Estes score has been shown to have a better correlation with echocardiographic hypertrophy than the latter in previous studies.[21,22] Even when applying ESC LVH criteria, the prevalence of LVH was still significantly higher than what was previously reported in similar study populations.[23] This could not be explained by adjusting R-wave amplitude by height, weight, BMI, and/or gender. The inclusion of many athletes participating in sports with a major impact on physiological cardiac remodeling may partly explain this high prevalence.[6,15] It has also been previously suggested that intensive training was more likely to alter the ECG patterns when associated with body growth during adolescence.[4] Conversely, T-wave inversion, the second most common major abnormality, was less frequently observed than in high school or in adult athletes.[5,24] The higher frequency of abnormal T waves in women, particularly in the precordial leads, has been described in adults.[25] This common finding in women is particularly important because it can be misinterpreted as a minor ESC ARVD/C criterion.[2] Abnormal Q waves were less frequently seen than in more senior athletes,[4] but similar rates were found in high school students.[24] Only 3 athletes presented isolated PVCs on the10-second ECG recording, which contrasts with their 5% prevalence found in an older clinic population and the 10% prevalence found in patients with heart failure.[26]

Less than 2% presented a pattern that could be suggestive of a malignant cardiac disease. The prevalence of the WPW pattern found in this study (2 athletes) is similar to findings in the trained adult and general population.[4,5] Less than 1% had a pattern suggestive of ARVD/C, which is much

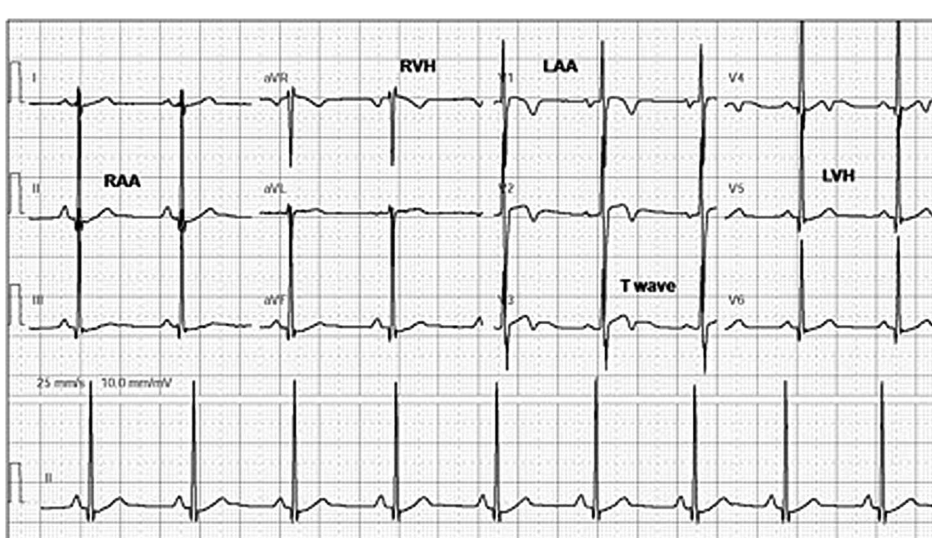

FIGURE 2. Example of a Stanford University distinctly abnormal electrocardiogram (ECG). This young female athlete presented multiple abnormalities: RAA, right atrial abnormality; LAA, left atrial abnormality; RVH, right ventricular hypertrophy; LVH, left ventricular hypertrophy; and T-wave inversion in ≥2 leads.

lower than in most Italian studies.[3] In Italy, ARVD/C is the most common cause of SCD in athletes, whereas in the United States, it accounts for approximately 4% of athletic deaths.[1]

Another important finding is the difference in prevalence of abnormal ECG among various sports. Football, crew, and track and field were the 3 disciplines with the highest prevalence of abnormal ECG, whereas sailing, wrestling, and gymnastics showed the lowest percentages. Abnormal and distinctly abnormal ECG and enlarged LV dimensions have been more frequently encountered in endurance sports.[4] It has been hypothesized that sprinting and bursts of sustained physical activity associated with abrupt changes in HR were associated with more abnormal ECG.[27] By ethnicity, ECG abnormalities have been found to be more common in African American than in white football players.[27,28] Such a difference was not found in this present study.

With Stanford-adapted criteria, 10% of athletes required further evaluation. Using Pelliccia et al[4] classification, more would require further investigation because 15% had distinctly abnormal ECG. The percentage of distinctly abnormal ECG obtained in our population is comparable to most Italian studies conducted in more senior athletes[4,27] or in unselected populations.[5] The high percentage of abnormalities seen in our population is again mostly attributed to the very high prevalence of LVH (with strain).

Considering the prevalence of diseases potentially associated with SCD and the important findings from the third of athletes with abnormal ECG who agreed to a follow-up cardiac MRI, it has been the consensus of the cardiologists at our institution to recommend that ECG screening becomes mandatory for our athletes and that those with abnormal ECG undergo further evaluation before being allowed to compete. Of note, our adoption of this approach is in line with that advocated by the AHA but may not be achievable in other collegiate settings.

Study Limitations

Because of the study design, we did not determine the final cardiac diagnosis for all individuals with abnormal ECG or history and physical findings at the PPE screening. Therefore, the prevalence of structural heart disease in subjects with ECG abnormalities remains unknown. So far, 21 of 24 athletes with the most abnormal ECG patterns have had normal cardiac MRIs and echocardiograms.

It is not surprising that Brugada and short and long QTc patterns were not noted in our study. The population prevalence of each of these conditions is estimated to be between 1:1000 and 1:20,000. However, the prevalence of many findings consistent with such malignant conditions can be underestimated due to the dynamic intermittent nature of these abnormalities.[29] Also, it is not yet clear how often the identification of a recognized ECG pattern, such as the WPW pattern, translates to a clinical diagnosis. The natural course of asymptomatic subjects presenting with these isolated *signs* remains to be defined.

Current ECG criteria for LVH such as the Sokolow-Lyon criteria and the Romhilt-Estes point score have all been shown to poorly correlate with morphologic hypertrophy.[30] Although voltage criteria have been used to predict SCD risk in children previously diagnosed with HCM,[31] ECG voltages and patterns have been shown to be an unreliable clinical marker for the magnitude of LV hypertrophy or outflow obstruction.[32] Some have even recommended avoiding voltage criteria in the screening of athletes.[19]

CONCLUSIONS

With the present study, we demonstrated the feasibility of mass ECG screening within the collegiate setting. Considering our overall experience, we now recommend that ECG screening becomes mandatory for our athletes and that those with abnormal ECG undergo further evaluation before being allowed to compete. However, the rate of secondary testing is likely to be significant if the current criteria for abnormal findings are applied to competitive college athletes, particularly male athletes. These findings have important implications for preparticipation CV screening of athletes. This rate of secondary testing mandates the need for an evaluation of cost-effectiveness for mass screening and the development of new athlete-specific ECG interpretation algorithms that may consider the age, sex, ethnicity, and sporting discipline. Such a development should serve to facilitate a more nuanced approach to the addition of the ECG to the PPE.

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