Electrocardiographic Screening in National Collegiate Athletic Association Athletes

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The most effective protocol for cardiovascular screening of competitive athletes remains highly controversial. This study was a prospective, multicenter trial of cardiovascular screening at 35 National Collegiate Athletic Association institutions. Screening included a standardized history and physical examination (PE) as recommended by the American Heart Association and a 12-lead electrocardiogram (ECG) at rest. Centralized electrocardiographic interpretation was provided using the Seattle criteria. Athletes with screening abnormalities underwent additional evaluation directed by the host institution medical team. Primary outcomes included the proportion of total and false-positive screens; the sensitivity, specificity, and positive predictive value of history, PE, and ECG; and the prevalence of serious cardiovascular disorders associated with severe morbidity or sudden cardiac death. From August 2012 to June 2014, 5,258 athletes from 17 intercollegiate sports were screened: 55% men (mean age 20.1 years), 73% Caucasian, 16% African-American, and 11% other/mixed race. At least 1 positive cardiac symptom or family history response was reported by 1,750 athletes (33.3%). PE was abnormal in 108 athletes (2.1%), and electrocardiographic abnormalities were present in 192 athletes (3.7%). Thirteen athletes (0.25%) were identified with serious cardiac conditions including hypertrophic cardiomyopathy (1), large atrial septal defect with right ventricular dilation (1), and ventricular pre-excitation (11). The false-positive rate for history was 33.3%, PE 2.0%, and ECG 3.4%. The sensitivity/specificity/positive predictive value for history was 15.4%/66.9%/0.1%, PE 7.7%/98.2%/0.9%, and ECG 100%/96.6%/6.8%. In conclusion, electrocardiographic screening in National Collegiate Athletic Association athletes has a low false-positive rate and provides superior accuracy compared with a standardized history and PE to detect athletes with potentially dangerous cardiovascular conditions. **(Am J Cardiol 2016;118:754−759)**

Sudden cardiac death (SCD) is a devastating event and the leading cause of death in college athletes during sports.[1−3] A 10-year analysis of all-cause mortality in National Collegiate Athletic Association (NCAA) athletes indicates that the annual risk of SCD is substantially higher than initial estimates, with the highest risk found in men (2.65/100,000), black athletes (4.65/100,000), and Division I men's basketball (19.2/100,000).[2] These rates occur despite each of the nearly 500,000 NCAA athletes receiving a required pre-participation evaluation consisting at minimum of a history and physical examination (PE). The most effective strategy for cardiovascular screening of young competitive athletes remains highly controversial. The American Heart Association (AHA) and American College of Cardiology (ACC) define cardiovascular screening as an initiative intended to prospectively identify or raise suspicion of previously unrecognized and largely genetic/congenital cardiovascular diseases known to cause sudden cardiac arrest and sudden death in young people.[4] The AHA/ACC promote use of a comprehensive personal and family history and PE as a potentially effective method to detect cardiovascular disease in athletes. Although mandatory screening with an electrocardiogram (ECG) is not recommended, the AHA/ACC support electrocardiographic screening where physician interest and local resources are in place to achieve sufficient quality control.[4] The purpose of this study was to evaluate and compare the accuracy of cardiovascular screening in NCAA athletes using a standardized history, PE, and ECG.

Methods

This study was a prospective, multicenter study of cardiovascular screening in NCAA athletes from August 2012 to June 2014. A total of 35 different NCAA

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Table 1
Personal and family history responses to the American Heart Association 12-point assessment

Personal and Family History Questions	Total Athletes (N = 5258)	Male Athletes (N = 2892)	Female Athletes (N = 2366)
≥ 1 Positive Personal or Family History Response	1750 (33.8%)	876 (30.3%)	874 (36.9%)
Have you ever experienced chest pain or discomfort with exercise?	387 (7.4%)	191 (6.6%)	196 (8.3%)
Have you ever passed out or nearly passed out?	599 (11.4%)	254 (8.8%)	345 (14.6%)
Have you ever had excessive shortness of breath or fatigue with exercise?	677 (12.9%)	313 (10.8%)	364 (15.4%)
Have you been told you have a heart murmur?	260 (4.9%)	146 (5.0%)	114 (4.8%)
Have you had high blood pressure?	154 (2.9%)	129 (4.5%)	25 (1.1%)
Does anyone in your family have hypertrophic or dilated cardiomyopathy, Long QT or Marfan syndrome, or other heart arrhythmia problems?	234 (4.5%)	101 (3.5%)	133 (5.6%)
Has anyone in your family (age<50) died suddenly or unexpectedly from heart disease?	191 (3.6%)	91 (3.1%)	100 (4.2%)
Has anyone in your family (age<50) been disabled from heart disease?	122 (2.3%)	65 (2.2%)	57 (2.4%)

institutions participated, including 13 division I institutions in year 1 and 13 division I and 12 division II or division III programs in year 2. Study recruitment for year 2 was intentionally expanded to include division II and III programs with potentially less cardiology resources. Any athlete ≥18 years without previous electrocardiographic screening or a known cardiovascular condition was eligible for the investigation. Participation in the study was voluntary, and each athlete underwent verbal and written informed consent.

The screening protocol included the AHA 12-point history questionnaire and PE and a 12-lead ECG at rest.[5] The study was conducted before publication of the updated AHA 14-point evaluation.[4] The cardiovascular examination included a brachial artery blood pressure at rest, cardiac auscultation, and recognition of the physical stigmata of Marfan syndrome. The cardiac history questions and PE were done at the time of the ECG or pre-participation evaluation, and positive findings recorded. ECGs were performed at each institution using standard 12-lead placement and a portable ECG machine (CardeaScreen, Seattle, Washington). Electrocardiographic data were de-identified and transmitted electronically over a secure portal for overread at the University of Washington. Electrocardiographic interpretation was performed by cardiologists with experience in electrocardiographic interpretation in athletes and guided by the Seattle criteria intended to distinguish physiological cardiac adaptations in athletes from electrocardiographic abnormalities associated with pathologic cardiac disorders.[6] The secondary evaluation of screening abnormalities detected by history, PE, or ECG was directed by the host institution medical team. Consultation with sports cardiology specialists at the University of Washington was available as requested.

Descriptive statistics such as proportions, means, and cross tabulations were used to analyze collected data. Symptom and family history responses, PE, and electrocardiographic findings were compared between student-athletes and statistical comparisons performed using independent *t* tests. Statistical significance was defined as a p value <0.05. Primary outcome measures as planned before data collection included: (1) the prevalence of detectable cardiovascular disease associated with severe morbidity or SCD; (2) the proportion of total and false-positive electrocardiographic screens and comparison with the AHA 12-point history and PE; (3) evaluation of sensitivity, specificity, and positive predictive value (PPV) for history, PE, and ECG; and (4) the performance of the Seattle criteria and examination of electrocardiographic abnormalities in NCAA athletes.

The study was approved by the Human Subjects Division at the University of Washington. A cooperative human subjects' agreement or letter of human subjects deferment to the principal investigatory site (University of Washington) was obtained from each participating institution.

Results

Thirty-five NCAA institutions and 5,258 athletes participated in the study. In year 1, athletes from 13 division I programs participated (n = 2,465), and in year 2, athletes from 25 division I/II/III institutions participated (n = 2,793). No athlete was screened in both years 1 and 2. The athletes were 55% men (n = 2,892) and participated in 17 different intercollegiate sports. The average age was 20.1 years (range 18 to 28). Race was self-reported and representative of the overall NCAA athletic population with 3,812 athletes Caucasian (73%), 853 African-American (16%), 151 Asian (2.9%), 248 Hispanic (4.7%), 81 Pacific Islander (1.5%), 15 Native American (0.3%), and 93 other or mixed race (1.8%). Race was not reported in 5 athletes.

Positive history responses on the AHA-12 point are listed in Table 1. At least 1 positive symptom or family history response was reported by 1,750 athletes (33.3%). Female athletes were more likely to report at least 1 positive cardiovascular symptom or family history response (36.9%) versus male athletes (30.3%; p <0.001).

PE was deemed abnormal in 108 athletes (2.1%), including 88 athletes (1.7%) with a heart murmur and 17 athletes (0.3%) with physical stigmata of Marfan syndrome. In addition, 283 athletes (5.4%) had an initial blood pressure >140 systolic and/or >90 diastolic (8.7% men, 1.4% women; p <0.001), and 30 athletes (0.6%) had an initial blood pressure >160 systolic and/or >100 diastolic (0.9% men, 0.1% women; p <0.001).

Electrocardiographic abnormalities were present in 192 athletes (3.7%) (Table 2). The rates of an abnormal ECG based on gender, race, and sport are shown in

Table 2
Specific electrocardiographic abnormalities

198 Abnormalities in 192 Athletes		
ECG Abnormality	N	% of 198 Abnormalities
Q Waves	72	36.4%
Anterior	8	4.0%
Inferior	28	14.1%
Lateral	45	22.7%
T Wave Inversion	38	19.2%
Anterior	19	9.6%
Inferior	11	5.6%
Lateral	12	6.1%
Left Axis Deviation	25	12.6%
ST Segment Depression	15	7.6%
Inferior	14	7.1%
Lateral	5	2.5%
Ventricular Premature Complexes	13	6.6%
Ventricular Pre-excitation	11	5.5%
Left Atrial Enlargement	8	4.0%
Prolonged QRS	3	1.5%
Right Ventricular Hypertrophy	5	2.5%
Prolonged QTc	4*	2.0%
Other	4	2.0%

* No athlete with a prolonged QTc on initial screening ECG was ultimately diagnosed with long QT syndrome.

Figures 1 and 2. There was a trend for African-Americans to have more abnormal ECGs compared with Caucasian athletes; however, this did not reach statistical significance (4.8% vs 3.4%; $p = 0.069$). Male basketball players had a higher rate of abnormal ECGs compared with female basketball players (10.3% vs 2.2%; $p < 0.001$) and other male athletes (10.3% vs 4.0%; $p < 0.001$). Compared with other male athletes, male basketball players more commonly exhibited abnormal T-wave inversion (ratio = 10.9; $p < 0.001$), ST-segment depression (ratio = 6.8; $p < 0.001$), and left-axis deviation (ratio = 5.0; $p < 0.01$).

The secondary evaluation of athletes with an abnormal ECG included echocardiography (135), cardiology consultation (108), exercise electrocardiographic testing (26), stress echocardiography (10), cardiac magnetic resonance imaging (9), electrophysiology study (1), ambulatory electrocardiographic monitoring (9), and multigated acquisition scan (1). The average time loss from sport to conduct secondary testing in athletes with electrocardiographic abnormalities was 2.6 days (range 0 to 75 days).

Thirteen athletes (0.25%) were identified with cardiac conditions associated with serious morbidity or SCD, including hypertrophic cardiomyopathy (1), a large atrial septal defect with right ventricular dilation requiring surgery (1), and ventricular pre-excitation (11). All athletes studied with a detected condition associated with SCD had an abnormal ECG, 2 had an abnormal history, and 1 had an abnormal PE (Table 3). Athletes with minor cardiac abnormalities were also detected and included 2 athletes with a bicuspid aortic valve and 1 athlete with mitral valve regurgitation. No adverse medical events from secondary cardiac testing or therapeutic procedures occurred in this cohort.

The false-positive rate for history using the AHA-12 point questions was 33.3%, PE 2.0%, and ECG 3.4%. The sensitivity/specificity/PPV to detect relevant cardiac conditions for history was 15.4%/66.9%/0.1%, PE 7.7%/98.2%/0.9%, and ECG 100%/96.6%/6.8%.

Discussion

Effective cardiovascular screening in competitive athletes remains a formidable challenge and area of vigorous debate. The prevention of SCD during sport is an important and common goal promoted by both the AHA and the European Society of Cardiology; however, the actual screening protocol is passionately disputed.[4,7] In a poll conducted by the *New England Journal of Medicine*, 24% of the 1,266 respondents favored pre-participation cardiac screening with a history and PE only, whereas 58% favored screening with a history, PE, and ECG.[8]

This study examines the traditional AHA 12-point history and PE versus the addition of ECG for cardiovascular screening in college athletes. This is the largest study of cardiovascular screening in college athletes, and the first prospective, multicenter study to investigate electrocardiographic screening across all 3 NCAA divisions with variable cardiology resources. The findings highlight that screening by history and PE alone has a low sensitivity to detect conditions associated with SCD and that ECG when properly interpreted by experienced clinicians improves cardiovascular screening if the measurable end point as stated by the AHA is considered the detection of silent/congenital cardiac conditions associated with SCD.

In this cohort, most subjects with serious cardiac conditions would have been missed if ECG were not included in the cardiovascular evaluation. In fact, 8 of the 13 subjects identified with cardiac disorders were upperclassmen who had already undergone standard pre-participation cardiovascular screening. The limitations of cardiovascular screening by history and PE alone was first reported in a 1996 study, where only 1 athlete of 115 who had SCD was diagnosed correctly through a pre-participation medical evaluation.[9] The challenge to detect potentially lethal conditions through symptom screening is further complicated by evidence that suggests up to 80% of athletes who had SCD have no preceding warning signs or symptoms.[9,10]

Data from this study demonstrate that ECG outperformed the AHA 12-point evaluation by all statistical measures of performance. However, the superior performance of ECG compared with history and PE does not in itself justify a recommendation for electrocardiographic screening in college athletes. Other critical factors, such as physician infrastructure, must be addressed to ensure that if ECG is included in the cardiovascular screening of athletes, that resources are available for both accurate electrocardiographic interpretation and the proper secondary evaluation of electrocardiographic abnormalities. This study was limited, in that it used only a single center for ECG overread and did not investigate the accuracy of electrocardiographic interpretation at each of the participating sites. Thus, additional research is needed to determine if quality electrocardiographic screening programs can be initiated across larger populations and at institutions with less experience.

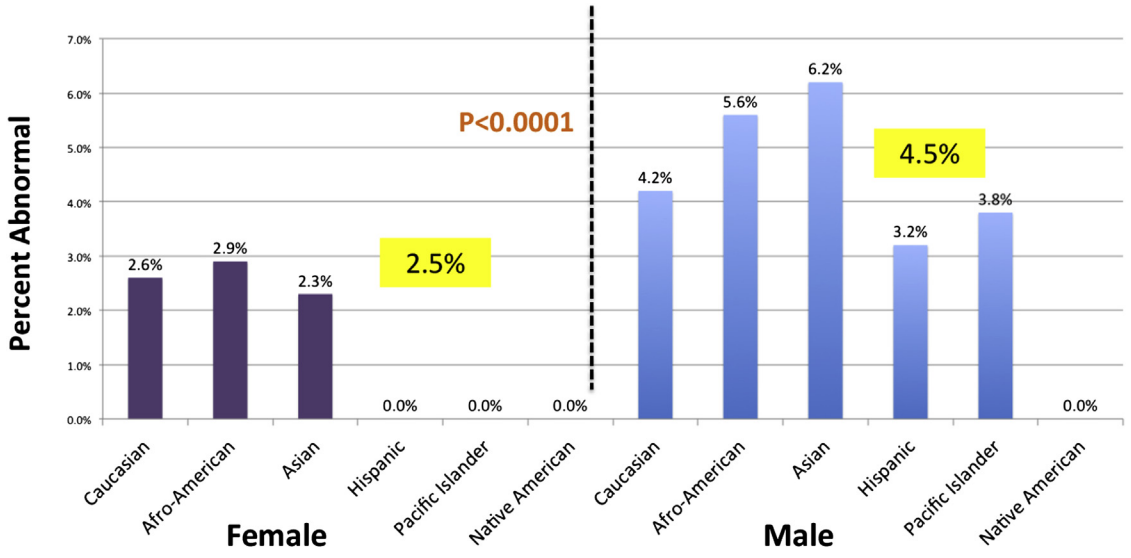

Figure 1. Rate of abnormal electrocardiograms by gender and race.

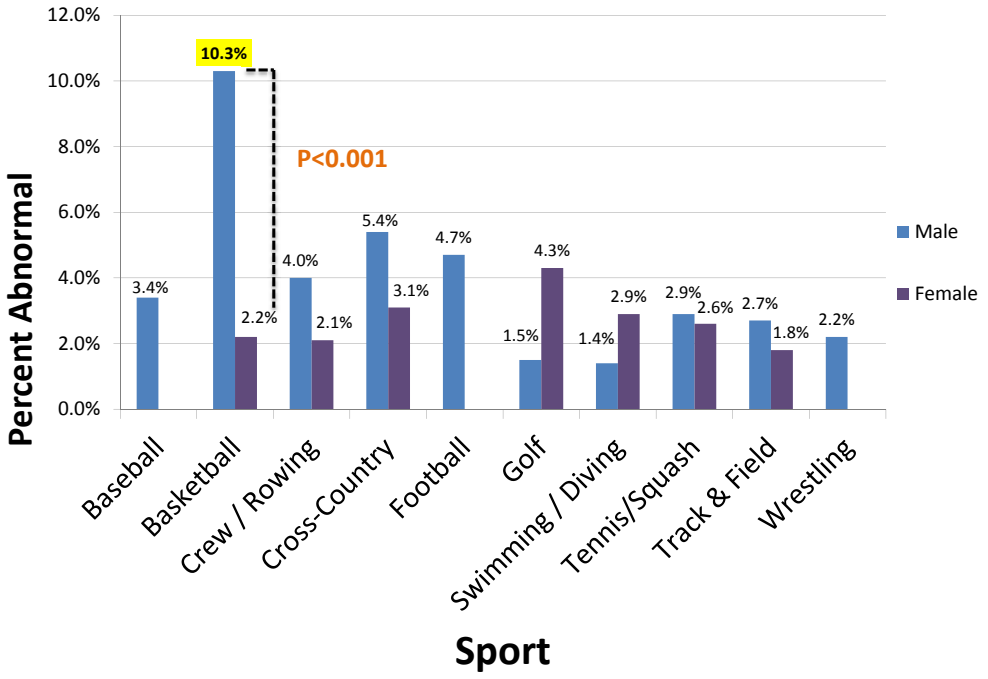

Figure 2. Rate of abnormal electrocardiograms in male and female sports.

However, this study does suggest that regional centers of excellence may provide a potential avenue for accurate electrocardiographic interpretation across interested institutions.[11]

No single test exists as a gold standard that will detect all cardiovascular disorders at risk of SCD. Thus, sensitivity and specificity calculations in this study were based on the disorders identified from the screening protocol and secondary investigations used. All studies of cardiovascular screening in college athletes have demonstrated that ECG greatly increases the likelihood of disease detection and that history and PE provide little contribution to the identification of athletes at risk.[12–16] It seems if cardiovascular screening in college athletes is recommended, that ECG-inclusive strategies represent best practice, and the objectives of screening by history and PE alone should be re-evaluated.

This study also highlights the rather vague nature and low yield of cardiac screening questionnaires. Over one third of athletes responded positively to one of the cardiac symptom or family history questions. Although concerns for false-positive results are frequently cited in opposition to electrocardiographic screening, this study demonstrates that the false-positive rate is actually 10 times higher for a

Table 3
Cardiac disorders associated with serious morbidity or sudden cardiac death

Final Diagnosis	Year	Gender/ Race	Sport	Abnormal History or PE	ECG Findings
HC	Fr	F / White	Swimming	(0)	Lateral Q waves, RAD
ASD with RV dilatation	So	M / Pac Isl	Football	(+) shortness of breath; murmur	LAD, incomplete RBBB
Ventricular pre-excitation - high risk pathway	Fr	F / White	Crew	(0)	Ventricular pre-excitation
Ventricular pre-excitation - high risk pathway	Se	M / White	Soccer	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	Fr	F / White	Crew	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	Jr	F / White	Crew	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	Jr	F / White	Tennis	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	So	F / White	Basketball	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	Fr	M / White	Baseball	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	So	M / White	Cheer	(0)	Ventricular pre-excitation
Ventricular pre-excitation - low risk pathway	Jr	M / White	Cross Country	(+) murmur	Ventricular pre-excitation
Ventricular pre-excitation - ?	Jr	M / White	Soccer	(0)	Ventricular pre-excitation
Ventricular pre-excitation - ?	Fr	M / Hisp	Tennis	(0)	Ventricular pre-excitation

ASD = atrial septal defect; Fr = freshman; HC = hypertrophic cardiomyopathy; Jr = junior; LAD = left axis deviation; Pac Isl = Pacific Islander; PE = physical examination; RAD = right axis deviation; RBBB = right bundle branch block; RV = right ventricular; Se = senior; So = sophomore.

standardized cardiac history questionnaire than for ECG interpreted using contemporary standards. Other studies using standardized cardiac questionnaires have also found a high positive response rate in young athletes, ranging 14% to 68%.[13,14,17,18] This study found the PPV for ECG to be 68 times higher compared with a reported cardiac symptom or positive family history (6.8% vs 0.1%). In other words, 1,000 athletes would have to respond positively on a cardiac questionnaire to identify 1 athlete with a condition of relevance versus evaluating 15 abnormal ECGs to identify 1 athlete with a pertinent cardiac disorder. Therefore, the history questions used for cardiovascular screening of athletes are in vital need of investigation to understand revisions that could improve their sensitivity and specificity. Recently, the AHA expanded their primary recommendations for screening from a 12-point to a 14-point assessment.[4] Although additional study is needed, it seems unlikely that simply asking more questions will improve the effectiveness of a screening history and PE when the tool itself has considerable limitations.

An additional limitation in this study is that the secondary evaluation of electrocardiographic abnormalities was not standardized across study sites and in some cases was inadequate by expert standards. For instance, 9 male, normotensive, African-American athletes (6 basketball and 3 football) had inferolateral T-wave inversion with or without ST-segment depression, an electrocardiographic pattern expressed in patients with apical hypertrophic cardiomyopathy that is difficult to diagnose by echocardiography alone.[19] Only 3 of these 9 athletes had a cardiac magnetic resonance imaging considered standard evaluation for this electrocardiographic phenotype. Therefore, important cardiac pathology may have been missed, and this study may have underestimated the prevalence of ECG-detectable conditions. Longitudinal follow-up also was not conducted to determine if athletes with markedly abnormal ECGs and normal cardiac imaging later developed morphologic manifestations of cardiomyopathy.[19,20] In addition, 2 patients with ventricular pre-excitation received no risk stratification even by noninvasive exercise electrocardiographic testing to determine if the accessory pathway had low-risk characteristics.[21]

Last, findings from this study may not be applicable to other athlete populations or at institutions with less experience in electrocardiographic screening or with limited sports cardiology resources. Larger studies are also needed to more accurately establish the prevalence of detectable cardiovascular diseases associated with SCD. Importantly, additional longitudinal studies are required to determine if early detection of cardiac disorders at risk for SCD will lower mortality in the targeted athlete population.

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Disclosures

The authors have no conflicts of interest to disclose.

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