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Electrocardiogram interpretation in NCAA athletes: Comparison of the 'Seattle' and 'International' criteria

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ABSTRACT

Background: Accurate electrocardiogram (ECG) interpretation in competitive athletes requires the distinction of physiological adaptations from findings suggestive of a pathological condition. The purpose of this study was to compare the performance of the Seattle Criteria to the International Criteria in a large dataset of NCAA athletes screened with an ECG.

Methods: ECGs from 5258 NCAA athletes who underwent prior ECG screening were re-examined by two experts in the field of sports cardiology and by ECG interpretation software by Cardea (© 2018 Cardiac Insight Inc.) using the Seattle and International Criteria. Each ECG was classified as normal or abnormal and the specific ECG abnormalities noted. Chi-squared analysis was used for statistical comparisons.

Results: The total number of ECGs flagged as abnormal by expert over-read decreased from 158 (3.0%) using the Seattle Criteria to 83 (1.6%) using the International Criteria ($p < 0.0001$). Likewise, the total number of abnormal ECGs using ECG interpretation software by Cardea decreased from 278 (5.3%) using Seattle Criteria programming compared to 134 (2.5%) using International Criteria programming ($p < 0.0001$). The most common ECG abnormality by expert over-read using the International Criteria was T wave inversion 40 (48%). The newer definition of pathological Q waves reduced the number of ECGs flagged as abnormal from pathologic Q waves from 69 (Seattle) to 11 (International) (84% reduction; $p < 0.0001$). Expert over-read using both criteria and both Cardea interpretation programs identified all 13 athletes with cardiac pathology associated with sudden cardiac death. Cardea software using the International Criteria had a higher false-positive rate (2.3%) than expert over-read (1.3%) ($p = 0.0001$).

Conclusions: Use of the International Criteria for ECG interpretation significantly reduces the total abnormal and false-positive ECG rates compared to the Seattle Criteria without compromising sensitivity. Cardea interpretation software performs well and may be a useful tool to assist clinicians.

Introduction

Sudden cardiac death (SCD) is the leading cause of death in young athletes during sport and exercise [1–3]. Pre-participation cardiovascular screening aims to identify athletes with conditions at risk for SCD and provide disease-specific management to lower cardiovascular morbidity and mortality [4]. Many screening programs include a resting electrocardiogram (ECG) to enhance detection of athletes with pathologic conditions associated with SCD. The majority of cardiac disorders predisposing to SCD, such as cardiomyopathies, ion channelopathies, and ventricular pre-excitation, have identifiable abnormalities on ECG [1,3,5]. However, interpretation of the athlete's ECG is nuanced, as many physiologic changes common to the well-conditioned heart can be misclassified as abnormal [6,7]. Thus, use of ECG screening by an untrained provider has the potential for high rates of false-positive results with both psychological and economic consequences [8].

Experts in the field of sports medicine and cardiology have addressed these challenges by developing standardized criteria to guide ECG interpretation in the athlete. Multiple iterations of ECG standards exist including the 2010 European Society of Cardiology (ESC) guidelines, 2013 Seattle Criteria, 2014 Refined Criteria, and 2017 International Criteria [6,7,9,10]. The evolution of scientifically-based ECG interpretation standards for athletes has readily improved specificity without compromising sensitivity [10–16]. In addition, novel ECG interpretation software that incorporates athlete-specific standards may enhance interpretation accuracy, although available systems have not been previously validated. The purpose of this study was to compare

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the performance of the Seattle Criteria to the International Criteria, both by expert over-read and contemporary ECG interpretation software, in a large dataset of NCAA athletes who underwent ECG screening.

Material and methods

This study uses a dataset of 5258 de-identified ECGs obtained in a prior, multi-center study of cardiovascular screening in NCAA athletes conducted from 2012 to 2014 [17]. In the previous study, college athletes 18 years or older without prior ECG screening or a known cardiovascular condition were eligible, and any athlete with an abnormal history, physical examination, or ECG based on the Seattle Criteria underwent a secondary evaluation guided by the host institution [17]. As a result, the dataset garnered from the previous study includes the screening ECGs as well as the diagnostic outcome for each student-athlete who underwent secondary testing.

Two authors (JMP and JAD) with significant experience in ECG interpretation in athletes interpreted all ECGs applying both the Seattle Criteria and the International Criteria. Each ECG was classified as normal or abnormal, and for abnormal ECGs the specific ECG abnormalities were detailed. Discrepancies in the classification of an ECG were resolved by discussion and when needed a third expert was consulted to determine the final classification.

The ECG dataset was also examined using interpretation software by Cardea (© 2018 Cardiac Insight Inc.). Cardea developed software programs using athlete-specific standards that closely paralleled the Seattle Criteria and later the International Criteria. The software reported each ECG as normal or abnormal and noted the specific ECG abnormalities when present.

Descriptive statistics such as proportions, means and cross tabulations were used to analyze collected data. Sensitivity and specificity were calculated based on the discovery of a condition associated with SCD. Chi-squared analysis was used for statistical comparisons with statistical significance set at $p < 0.05$ (https://www.medcalc.org/).

This research involved the use of non-identifiable coded data with no link to the identity of the study subjects. Participation in the NCAA screening study was voluntary, included verbal and written informed consent, and was approved by the Human Subjects Division at the University of Washington [17].

Results

The study included 5258 athletes from 35 different NCAA institutions that participated in 17 intercollegiate sports. The cohort, was 55% male, with an average age of 20.1 years (range 18–28). Race was self-reported as 73% Caucasian, 16% African-American, 2.9% Asian, 4.7% Hispanic, 1.5% Pacific Islander, 0.3% Native American, and 1.8% mixed or other race [17].

The classification of ECGs as normal or abnormal is shown in Fig. 1. Of the 5258 ECGs, the total number of ECGs flagged as abnormal by expert over-read decreased from 158 (3.0%) using the Seattle Criteria to 83 (1.6%) using the International Criteria ($p < 0.0001$). Likewise, the total number of abnormal ECGs using interpretation software by Cardea decreased from 278 (5.3%) using Seattle Criteria programming compared to 134 (2.5%) using International Criteria programming ($p < 0.0001$). Expert over-read had a lower number of abnormal ECGs compared to the Cardea software program for both criteria ($p < 0.0001$). The most common ECG abnormality by expert over-read using the International Criteria was T wave inversion 40 (48%) followed by ventricular pre-excitation 12 (14%) (Table 1). The new definition of pathological Q waves used in the International Criteria reduced the number of ECGs flagged as abnormal from pathologic Q waves from 69 (Seattle) to 11 (International) (84% reduction; $p < 0.0001$). No athlete had two or more borderline findings per the International Criteria to classify the ECG as abnormal.

Compared to Caucasian athletes, African-American athletes had a higher proportion of abnormal ECGs irrespective of the ECG standard (Table 2). For African-American athletes, there was no difference in the proportion of abnormal ECGs using the International Criteria comparing Cardea interpretation software and expert over-read ($p = 0.63$) (Table 3). However, using the Seattle Criteria the Cardea interpretation software demonstrated a higher proportion of abnormal ECGs in African-American athletes compared to expert over-read ($p = 0.03$).

Expert over-read using either the Seattle or International Criteria as well as both Cardea interpretation programs identified all 13 athletes with cardiac disorders associated with SCD. The false-positive rate for expert over-read using the Seattle Criteria was 2.8% and for the International Criteria was 1.3% (Fig. 1). The false-positive rate for the Cardea software was 5.0% for the Seattle Criteria and 2.3% for the International Criteria. For the International Criteria, Cardea software had a significantly higher false-positive rate than expert over-read ($p = 0.0001$). Using the International Criteria, 1 in 6 abnormal ECGs by expert over-read was a true positive, while 1 in 10 abnormal ECGs as flagged by Cardea programming represented a disorder implicated in SCD.

Discussion

Cardiovascular causes of sudden death represent 75% of all fatalities in young athletes during sports [1]. Cardiovascular screening aimed at the identification of athletes with disorders at risk of SCD is widely supported, yet the use of ECG as a screening tool has been heavily debated [4,8,18–21]. The European Society of Cardiology supports the routine use of ECG for cardiovascular screening, while the American Heart Association has opposed routine use of ECG due to the potential high false-positive rate, subsequent downstream cost of secondary investigations, limited sports cardiology infrastructure, and the possibility of temporarily or permanent disqualification of athletes who do not have cardiac disease [8,18]. However, screening by history and physical examination has been shown in multiple studies to be insufficient for the detection of cardiac conditions predisposing to SCD [4,22–26].

At the center of the screening debate is the concern for high false-positive rates if using ECG. To address this issue, experts in the field of

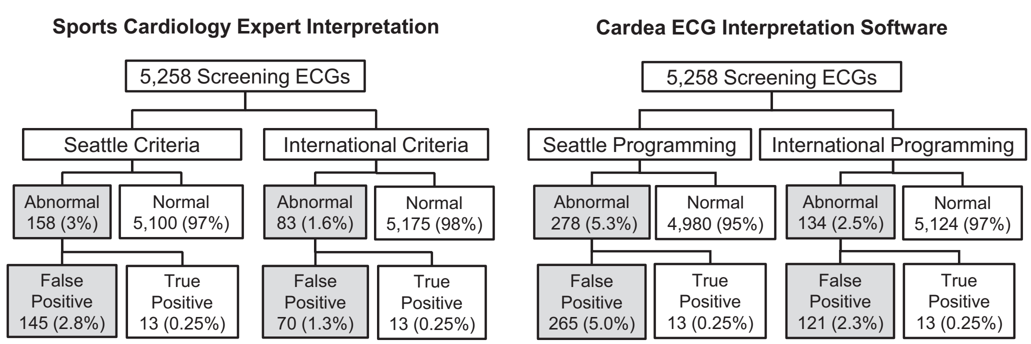

Fig. 1. Electrocardiogram interpretation in college athletes by expert over-read and Cardea software. ECGs = electrocardiograms.

Table 1
Specific electrocardiogram abnormalities in college athletes using different interpretation systems.

Electrocardiogram abnormality	Seattle Cardea $N = 278$	Seattle expert $N = 158$	International Cardea $N = 134$	International expert $N = 83$
T wave inversion	61 (22%)	42 (27%)	34 (25%)	40 (48%)
Anterior	27 (9.7%)	21 (13%)	20 (15%)	18 (22%)
Lateral	12 (4.3%)	8 (5.1%)	5 (3.7%)	10 (12%)
Inferolateral	6 (2.2%)	5 (3.2%)	6 (4.5%)	5 (6.0%)
Inferior	16 (5.8%)	8 (5.1%)	3 (2.2%)	7 (8.4%)
ST segment depression	16 (5.8%)	17 (11%)	8 (6.0%)	8 (9.6%)
Pathological Q waves	99 (36%)	69 (44%)	6 (4.5%)	11 (13%)
Prolonged QRS	10 (3.6%)	3 (1.9%)	4 (3.0%)	4 (4.8%)
Ventricular pre-excitation	12 (4.3%)	12 (7.6%)	12 (9.0%)	12 (14%)
Prolonged QT interval	3 (1.1%)	4 (2.5%)	3 (2.2%)	0
Profound 1° AV block	0	0	0	1 (1.2%)
Atrial tachyarrhythmias	4 (1.4%)	0	5 (3.7%)	0
Premature ventricular contractions	17 (6.1%)	12 (7.6%)	13 (9.7%)	11 (13%)
Left axis deviation	25	24	24	[b]
Left atrial enlargement	35	8	24	[b]
Right axis deviation	10	2	9	[b]
Right atrial enlargement	3	1	3	[b]
Complete RBBB	7	3	15	[b]
Right ventricular hypertrophy	6	4	5	[b]
Total ECG abnormalities[a]	308	201	165	87

AV = atrioventricular; RBBB = right bundle branch block.
[a] Multiple ECGs had one more than one ECG abnormality.
[b] Not flagged as an abnormal ECG using the International Criteria. No athlete had two or more borderline findings per the International Criteria.

sports cardiology collaborated to develop consensus, data-driven ECG interpretation standards that differentiate physiologic from pathologic ECG findings with the intent of improving specificity while maintaining sensitivity [6,7]. This study compared the accuracy of ECG interpretation using the 2013 Seattle Criteria and the 2017 International Criteria in a large cohort of college athletes. Additionally, this is the first study to critically examine automated ECG interpretation software by Cardea.

Use of the International Criteria for ECG interpretation significantly reduced the total abnormal and false-positive rates compared to the Seattle Criteria. Importantly, all 13 athletes previously identified as having cardiac pathology at risk for SCD were identified using both criteria. African-American athletes demonstrated a higher proportion of ECG abnormalities consistent with prior studies [10,17,27–29].

One significant change moving from the Seattle Criteria to the International Criteria was a new definition for pathologic Q waves. In the Seattle Criteria, pathologic Q waves are defined as >3 mm in depth or >40 ms in duration in two or more leads (excluding leads III and aVR) [6]. In the International Criteria, pathologic Q waves are defined as a Q/R ratio ≥0.25 or a Q wave ≥40 ms in duration in two or more leads (excluding III and aVR) [7]. This change resulted in an 84% reduction of false-positive ECGs due to pathologic Q waves. Changing to a Q/R ratio reduces the effects of increased QRS voltage secondary to athletic remodeling and/or low impedance in lean individuals [30]. Importantly, athletes from this cohort with pathologic Q waves as defined by the Seattle Criteria did undergo cardiac imaging with an echocardiogram without the identification of corresponding cardiac pathology [17]. Thus, false-positives from narrow Q waves >3 mm are a reflection of high QRS amplitude rather than a marker of pathology.

This study also examined ECG interpretation software utilized by the Cardea device to facilitate ECG interpretation in athletes. Cardea interpretation software successfully flagged as abnormal ECGs from all 13 athletes discovered to have cardiac pathology concerning for SCD. Cardea software using the International Criteria also provided similar accuracy compared to expert over-read in African-American athletes, a subpopulation of athletes that demonstrates a higher proportion of ECG abnormalities. While Cardea had a higher false-positive rate compared to expert over-read, it demonstrated only a 2.3% false-positive rate using the International Criteria program. Thus, Cardea may represent a beneficial tool to make accurate ECG interpretation more widely available if there is not local ECG reading expertise, and having equivalent sensitivity to expert interpretation raises the possibility of conducting ECG over-read only for ECGs flagged by Cardea as abnormal. While reducing the need for physician over-read in approximately 97% of screened athletes may make ECG screening more cost-effective, this model requires additional investigation.

Limitations

This study had several limitations that should be recognized. First, the low false-positive rates achieved by expert over-read in this study may not be reproducible by clinicians with less ECG interpretation experience. Free, online ECG interpretation training modules based on the International Criteria have been developed and are open access (https://uwsportscardiology.org/E-Academy), but accurate ECG interpretation in practice likely requires additional clinical experience. This study also was conducted in college-aged athletes, and thus findings may not be applicable in younger or older athletes. Larger study would further validate findings in African-American athletes and other racial minorities. In addition, only the Cardea software was investigated, and similar accuracy should not be expected if using other automated interpretation programs.

Table 2
Proportion of abnormal electrocardiograms in African-American versus Caucasian athletes.

	African-American vs. Caucasian Athletes	*P* value	95% confidence interval
International expert	2.9% vs. 1.4%	0.002	0.476% to 2.893%
International Cardea	3.3% vs. 1.6%	0.001	0.599% to 3.167%
Seattle expert	4.8% vs. 3.4%	0.049	0.009% to 3.131%
Seattle Cardea	7.3% vs. 5.0%	0.007	0.573% to 4.349%

Table 3
Proportion of abnormal electrocardiograms in African-American athletes for Cardea versus expert over-read.

	Cardea vs. Expert	P value	95% confidence interval
International criteria	3.3% vs. 2.9%	0.63	−1.287% to 2.102%
Seattle criteria	7.3% vs. 4.8%	0.03	0.230% to 4.807%

Conclusion

The evolution of ECG interpretation standards for athletes has readily improved specificity without compromising sensitivity. The International Criteria establish a low abnormal and false-positive rate without a loss in sensitivity to detect conditions at risk of SCD. As sports cardiology infrastructure and training continue to advance, contemporary interpretation software using athlete-specific standards provides an acceptable starting point, especially for clinicians with less experience.

Declaration of Competing Interest

None of the authors have a financial conflict of interest to disclose. JAD is the Medical Director and JMP is on the Medical Advisory Committee for the Nick of Time Foundation.

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