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The International Criteria for Electrocardiogram Interpretation in Athletes:

Common Pitfalls and Future Directions

Bradley J. Petek, MD[a,b], **Jonathan A. Drezner, MD**[c], **Timothy W. Churchill, MD**[a,b,*]

[a]Division of Cardiology, Massachusetts General Hospital, 55 Fruit Street, Boston, MA 02114, USA

[b]Cardiovascular Performance Program, Massachusetts General Hospital, Yawkey Suite 5B, 55 Fruit Street, Boston, MA 02114, USA

[c]University of Washington Medical Center for Sports Cardiology, Massachusetts General Hospital, 3800 Montlake Boulevard Northeast, Box 354060, Seattle, WA 98195, USA

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INTRODUCTION

Preparticipation cardiovascular screening (PPCS) in young competitive athletes is performed to detect conditions associated with sudden cardiac death (SCD). Many medical societies and sports governing bodies recommend PPCS consisting of a focused history and physical examination (H&P) and 12-lead electrocardiogram (ECG).[1-6] Initial ECG screening was criticized for high false-positive rates that led to substantial costs associated with secondary testing and unnecessary (temporary) restriction of athletes from participation. This led to substantial efforts by the scientific community to better understand the difference between physiologic and pathologic ECG findings in athletes. Beginning with the 2010 European Society of Cardiology (ESC) guidelines, several iterations of ECG interpretation standards have emerged, culminating in the most updated ECG interpretation criteria, the International Criteria.[7-12] Since the initial publication of the International Criteria in 2017, multiple studies have shown improved diagnostic accuracy (improved specificity without compromising sensitivity) in different athletic populations. In this review, we present common pitfalls for ECG interpretation in athletes using the International Criteria and highlight future directions to consider in subsequent iterations of ECG screening standards.

*Corresponding author. Cardiovascular Performance Program, Massachusetts General Hospital, Yawkey Suite 5B, 55 Fruit Street, Boston, MA 02114. twchurchill@partners.org Twitter: @TimChurchillMD (T.W.C.).

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EVOLUTION OF ELECTROCARDIOGRAM SCREENING CRITERIA IN ATHLETES

ECG screening among athletic populations first emerged with a New England Journal of Medicine publication by Corrado and colleagues on ECG screening for hypertrophic cardiomyopathy in young athletes.[13] This was followed several years later by a broader and more systematic approach proposed by the ESC in 2005[10] with the publication of the first standardized ECG screening criteria in athletes, and multiple subsequent iterations have followed.[7-12] The initial ESC 2005 criteria provided a list of "abnormal" ECG findings in athletes that warranted further evaluation. A series of National Collegiate Athletic Association articles using these criteria found high rates of abnormal ECGs and false-positive rates (>10%),[14-17] which led to increased scrutiny of how ECG screening may lead to unnecessary secondary testing and significant costs on the medical system. The ESC subsequently proposed new criteria in 2010 that introduced the concept of "common/training-related" ECG patterns, in contrast to more concerning "uncommon/ training-unrelated" findings.[7] Although the incorporation of normal training-related ECG findings improved the diagnostic performance of ECG interpretation in athletes, studies using these criteria reported high rates of abnormal ECGs (3%–47%) and false-positive rates (5%–60%) depending on the patient population assessed.[9,18-34] One of the notable features of these criteria was that they were derived from largely Caucasian cohorts and accordingly did not account for emerging data describing common repolarization abnormalities among Black athletes.[35]

The Seattle Criteria were created in 2013 to update interpretation standards inclusive of ethnic-specific ECG findings and provide a pragmatic approach for the sports medicine and cardiology communities.[8] A major addition in this iteration was the recognition that convex (domed) ST elevations followed by T wave inversion (TWI) in V1 to V4 represents a normal, nonpathologic finding in Black athletes.[35] The Seattle criteria also presented important changes in definitions of pathologic Q waves, TWI, ST-segment depressions, left axis deviation, right axis deviation, ventricular preexcitation, short QT, Brugada syndrome, nonspecific intraventricular conduction delay, and arrhythmias. These criteria significantly improved false-positive rates, reported between 2% and 22% depending on the population studied.[9,19,25,26,30,32,36,37]

After the publication of the Seattle Criteria, subsequent studies showed that isolated voltage criteria for atrial enlargement and axis deviation correlated poorly with underlying cardiac disorders in asymptomatic athletes.[38] This recognition led to publication of the Refined Criteria in 2014, which included a borderline group of ECG patterns (left atrial enlargement, right atrial enlargement, left axis deviation, right axis deviation, right ventricular hypertrophy, Black athlete repolarization pattern), whereby the presence of 2 or more borderline ECG findings warranted further evaluation.[9] With this change, the Refined Criteria once again lowered the reported false-positive rate to 3% to 16%.[9,25,30,39]

The International Criteria are the most recent iteration of ECG interpretation guidelines in athletes and were created in 2017 by an international panel of experts in cardiology and sports medicine.[11] Notable changes in the International Criteria included a change in the

definition for pathologic Q waves, recognition of juvenile TWI in V1 to V3 as a normal finding in athletes aged younger than 16 years, and addition of epsilon waves and TWI 1 mm or greater in V5 or V6 alone to the "abnormal" category.[40] Multiple large-scale screening studies have assessed the diagnostic accuracy of the International Criteria and have reported lower false-positive rates ranging from 1.3% to 6.8%.[25,26,41-43] Notably, one of the higher reported false-positive rates (6.8%) was reported in a 2019 study, by McClean and colleagues, which included 1304 Arab and Black athletes in Qatar, highlighting the need for ongoing study to better refine ECG criteria across diverse populations.[26] In contrast, Hyde and colleagues reported a false-positive rate of only 1.3% among 5258 college athletes with application of the International Criteria by sports cardiology experts.[41] Several subsequent studies have been performed in unique demographic populations and sporting disciplines to further characterize the utility of the International Criteria in specific athlete cohorts and have identified populations where the ECG criteria perform well and others that may require further refinement.[22,25,26,41-73]

COMMON PITFALLS

Although the publication of the International Criteria has significantly reduced false-positive rates for ECG interpretation in athletes, there are still ECG patterns that are frequently misclassified by clinicians, particularly those without experience in the interpretation of athlete ECGs. Multiple previous studies have shown that physicians with limited experience in ECG interpretation in athletes will incorrectly classify a large proportion of normal ECGs in athletes as abnormal,[74-77] which can lead to downstream costs from secondary testing and unnecessary sport restriction and psychosocial burden on athletes.[77] However, when physicians are instructed to use a standardized ECG interpretation tool, there is improved accuracy.[60,75]

In studies which have compared local ECG interpretation to an expert overread, ECG findings that are commonly misinterpreted by local providers as abnormal include: LVH (left ventricular hypertrophy), nonpathologic TWI, isolated axis deviation, IVCD less than 140 milliseconds, RBBB in isolation, misinterpreted accessory pathway, nonpathologic rhythm variants, PVCs (<2 per strip), first-degree AV block, and J-waves.[45,47] In contrast, ECG findings classified as normal by local providers but readjudicated as abnormal by expert overread include: pathologic TWI, biatrial enlargement, pathologic Q waves, pathologic ST-segment depressions, and atrial tachyarrhythmias.[45,47] These studies highlight the importance of continual medical education for clinicians using ECG in the cardiovascular care of athletes. This education can occur via in-person educational courses with content experts, online training courses (https://uwsportscardiology.org/e-academy/), or other educational materials. An overview of commonly misclassified ECG abnormalities using the International Criteria for ECG interpretation is presented in Table 1. Examples of ECGs commonly misclassified are presented in Figs. 1-4.

FUTURE DIRECTIONS

Although the International Criteria outperform all previous ECG interpretation standards in athletes, there is scope for improvement as new evidence emerges (Table 2). Ideally, ECG

interpretation criteria would be individualized for the demographic and sport of each athlete. However, making the criteria too complex also limits the ease of use and application in everyday practice. Therefore, trade-offs are needed that maximize sensitivity/specificity in unique populations but also maintain user-friendly criteria, particularly when applied outside of expert centers. In the following sections, we present future considerations for subsequent ECG interpretation standards.

Race/Ethnicity/Geographic Origin-Specific Electrocardiogram Criteria

The first race-specific ECG criterion was the Black athlete repolarization pattern (convex/"domed" ST elevations followed by TWI in V1–V4) included in the 2013 Seattle Criteria, given the absence of pathologic findings in studies performing comprehensive cardiovascular testing in athletes with this pattern.[11,35] Although the recognition of this pattern reduced false-positive rates, the use of race to delineate all Black athletes has recently been challenged. In a study by Riding and colleagues involving 1698 mixed sport athletes, the authors observed significant differences in benign TWI patterns (V1–V4) in Black athletes based on geographic origin (Middle African 11.8%, West African 5.3%, African-American/Caribbean 2.4%, East African 1.5%, North African 0%).[72] The authors conclude that because there is heterogeneity in the prevalence of benign TWI patterns between the athlete cohorts, larger subgroups based on geographic origin should be studied before it is concluded that this repolarization pattern can be generalized to all Black athletes.

This repolarization pattern has also been characterized in non-Black athletes. Calore and colleagues compared anterior TWI in 80 athletes (66% Black) to 153 patients with hypertrophic or arrhythmogenic cardiomyopathy.[78] Cardiomyopathy was completely excluded in athletes with a combination of J-point elevation 1 mm or greater and TWI not extending beyond V4, regardless of race. These findings require additional investigation in larger cohorts of athletes with different race/ethnicity and geographic origin.

Since the publication of the International Criteria in 2017, multiple subsequent studies assessed these criteria in populations of athletes from all over the world including the United States,[41,42,44-49] the United Kingdom,[22,25,50-52] the Netherlands,[53] Macedonia,[54] Poland,[55] Italy,[43,56-58] Switzerland,[43,59,60] China,[61] Malaysia,[62-64] Pacific Islands,[65,66] Ecuador,[67] Argentina,[68] Qatar,[26,72,79] Ghana,[69,73] Cameroon,[70] and Nigeria.[71] Within these, rates of abnormal ECGs based on the International Criteria have varied widely. Athlete cohorts with high rates of abnormal ECGs have included Ghanian male soccer players (23.3%),[73] Malaysian male soccer players (20%),[64] United States National Basketball Association male players (15.6%),[46] Cameroonian male ultramarathoners (13.6%),[70] Middle African male athletes from the Qatar Olympic Committee (11.9%),[72] United States national team female soccer players (11.5%),[44] and Caucasian male professional cyclists (9.3%).[59] In contrast, populations with low rates of abnormal ECGs include US collegiate athletes (1.5%–2.1%)[41,42,45,48] and UK soccer players (1.8%).[25]

Given this persistent heterogeneity, it is clear that the generation of high-quality data from a diverse collection of source populations is required, with an emphasis on data defining not only race but geographic origin when possible. Such data will allow future iterations of ECG

interpretation criteria to more explicitly consider race/ethnicity and geographic origins in the creation of specific recommendations.

Age-Specific Electrocardiogram Criteria

Previous iterations of ECG screening criteria have been developed for the screening of asymptomatic athletes aged older than 12 years and younger than 35 years.[8,11] More research is needed to understand if the International Criteria can be applied to younger athletes aged less than 12 years or if specific modifications of the criteria are needed. Preliminary studies have shown that these ECG screening criteria may also be effective in Master's athletes (age >35 years).[53] As the International Criteria have been specifically curated for athletes aged 35 years or younger, extrapolation to older populations requires additional study and consideration.

Sex-Specific Electrocardiogram Criteria

Although it is well established that female athletes have different ECG features compared with male athletes,[80] the only sex-specific recommendation in the International Criteria pertains to outpoints for an abnormal corrected QT segment (QTc), defined in female athletes as 480 milliseconds or greater and in male athletes as 470 milliseconds or greater. Of specific interest in the screening setting is that female athletes, especially female endurance athletes, frequently have a higher percentage of anterior TWI (V1–V3). In studies assessing sex-based differences in ECG patterns, the prevalence of anterior TWI in female athletes ranges from 2% to 9%,[25,44,81-83] and anterior TWI in this population are unlikely to represent underlying cardiac pathologic condition.[25,44,83] Therefore, the presence of anterior TWI in female athletes may be a normal finding not warranting additional investigation. It has also been speculated that ECG lead placement may differ between male and female athletes due to the presence of breast tissue, particularly in the setting of large screening events in which ECGs are often not performed in completely private environments. Added consideration of sex differences in the interpretation of anterior TWI thus represents an important focus for future research.

Low QRS Voltage

Low QRS voltage is typically defined as a QRS amplitude of less than 0.5 mV in all 6 limb leads or less than 1 mV in the precordial leads.[84] Other definitions including the total sum of limb leads less than 3.0 mV have also been used. However, low voltage should also be considered in those with significant interval decreases in QRS voltage on 2 consecutive ECGs, in which case, the difference may suggest interval development of a pathologic condition. Although low voltage can be secondary to many cardiac and noncardiac causes (eg, obesity, emphysema), in competitive athletes important causes of SCD, which may demonstrate low QRS voltage, include arrhythmogenic right ventricular cardiomyopathy (ARVC),[85] myocarditis,[86] nonischemic LV scar, and infiltrative cardiac diseases. These conditions have increased electrical impedance where replacement fibrosis and the loss of electrically active myocardial mass lead to low QRS voltages.

Recent studies have suggested that a low voltage QRS can help differentiate ARVC from electrocardiographic remodeling in athletes.[87,88] In a study by Brosnan and colleagues of

100 healthy athletes matched with 100 ARVC patients both with TWI in at least 2 anterior ECG leads (V1-V4), the ARVC patients had a greater prevalence of low voltage in the limb leads (21% vs 1 %, $P < .001$), as well as more frequent precordial TWI beyond V3 (34% vs 8%, $P < .001$), inferior TWI (31% vs 3%, $P < .001$), and PVCs (18% vs 0%, $P < .001$).[88] The authors conclude that low QRS voltages may be an additional finding to differentiate healthy athletes from those with ARVC. A subsequent study by Finocchiaro and colleagues replicated this finding, comparing 162 patients with ARVC to 129 young controls with anterior TWI, again demonstrating an increased prevalence of low limb lead QRS voltage in the ARVC patients compared with controls (15% vs 4%, $P = .01$).[87] Among Olympic athletes (n = 516), Mango and colleagues found low QRS amplitude, defined here as either QRS amplitude of less than 0.5 mV in all 6 limb leads or less than 1 mV in the precordial leads, to be present in 4% of athletes but did not find any significant associations with pathologic condition.[89] In another recent study, Zorzi and colleagues compared the prevalence of low QRS voltage in the limb leads (all <0.5 mV) between Italian athletes (n = 2229), Black athletes (n = 1115), general population patients (n = 1115), and patients with known arrhythmogenic cardiomyopathy (AC) or nonischemic LV scar (NILVS, n = 58).[90] The key finding of this article was a low prevalence of low QRS voltage in athletes compared with the AC and NILVS patients (1.1% vs 12%). In addition, the authors also noted that 2/5 (40%) athletes with low QRS and exercise-induced ventricular arrhythmias were found to have a cardiomyopathy on cardiac MRI (1 AC, 1 NILVS). The authors therefore conclude that low QRS voltage should be considered in future iterations of ECG screening criteria.

Low QRS voltage has also been found in patients with myocarditis in the general population.[91] Additional study is required to define the clinical implications of low QRS voltage and to determine whether it merits inclusion in future iterations of ECG interpretation criteria.

QRS Fragmentation

Fragmentation of a narrow QRS is defined as the presence of an additional R wave (R′), notching in the nadir of the S wave or the presence of greater than 1 R′ in 2 contiguous leads (Fig. 5).[92] Conversely, fragmentation of a wide complex QRS has been defined as greater than 2 R waves (R″), more than 2 notches in the R wave, or more than 2 notches in the downstroke or upstroke of the S wave.[92] Previous studies have shown that QRS fragmentation is associated with and often predicts poor prognosis in many cardiac diseases including chronic coronary artery disease (myocardial scar),[93] dilated cardiomyopathy,[94] ARVC,[95] cardiac sarcoidosis,[96] and Brugada syndrome.[97] Of specific interest in the athletic populations would be if flagging QRS fragmentation aids in the detection of cardiomyopathies during PPCS.

Although QRS fragmentation has been associated with ARVC, the diagnostic performance of this finding seems to be limited. Notably, this ECG abnormality has not been included in the current or previous diagnostic criteria for ARVC.[98,99]

Limited studies have assessed the utility of QRS fragmentation in the diagnosis of underlying cardiac disorders in athletes. Recent study by Ollitrault and colleagues

demonstrated that QRS fragmentation in V1 ($fQRS_{V1}$) was more common in athletes than nonathletes (22% vs 5%, $P < .001$). Within this group, athletes with $fQRS_{V1}$ (n = 26) showed significant structural differences compared with athletes without $fQRS_{V1}$ (n = 93), including greater indexed right ventricular outflow tract (RVOT) dimensions, indexed RV basal diameter, tricuspid annular planar systolic excursion, indexed LV end diastolic diameter, and indexed LV mass.[100] The authors therefore conclude that $fQRS_{V1}$ is common among healthy athletes and may be considered a sign of RV remodeling, although this study did not provide any broader clinical or genetic correlation. Although this study suggests QRS fragmentation is common in healthy athletes and may not be a good distinguisher of disease, this study focused on QRS fragmentation in lead V1 only and larger scale studies are needed because earlier studies comparing ECG findings in athletes to patients with ARVC have not reported the presence or absence of QRS fragmentation.[87,88] Although QRS fragmentation is easily recognizable, it remains unknown if it would provide additive diagnostic value above and beyond the current criteria.

Premature Ventricular Contractions

The current International Criteria recommend further evaluation for all athletes who have 2 or greater premature ventricular contractions (PVCs) on a 10-second ECG.[11] Although PVCs can be a marker of myocardial disease, the chosen cutoff is arbitrary and does not consider PVC morphology, which can be an important diagnostic and prognostic marker.[101]

The morphology of PVCs can help to identify the anatomic origin of the ectopic beats, which has important implications for the likelihood of underlying cardiovascular disease. In athletes, infundibular right ventricular outflow tract and left ventricular outflow tract (RVOT and LVOT) and fascicular (left anterior and posterior) PVC origins are frequently seen and usually considered to be benign. RVOT PVCs are characterized by an LBBB pattern, inferior axis, and late precordial transition (R/s = 1 after V3; Fig. 6), whereas LVOT PVCs are characterized by an LBBB pattern, inferior axis, and early precordial transition (R/s = 1 by V2 or V3). Fascicular PVCs are characterized by a typical RBBB and QRS duration less than 130 milliseconds (anterior = inferior axis, posterior = superior axis). In contrast, patterns concerning for underlying myocardial disease in athletes include an atypical RBBB with QRS 130 milliseconds or greater (suggestive of mitral valve annulus, papillary muscles, or left ventricular sites of origin; Fig. 7) or an LBBB pattern with superior or intermediate axis (right ventricular free wall, interventricular septum).[102]

The prevalence of PVCs in young competitive athletes versus sedentary controls has been evaluated in many studies with mixed results.[103-107] Most studies were in small populations and have shown similar overall burden of PVCs in athletes as in control populations.[103,104,106] However, in a recent study by Zorzi and colleagues assessing the burden of PVCs and arrhythmias in athletes (n = 288) versus controls (n = 144), the presence of 1 or greater PVC on 24-hour 12-lead ECG monitoring was higher in the athlete cohort (59% vs 40%, $P < .0001$).[107] Although athletes may have a higher prevalence of PVCs depending on the study, studies have consistently shown that frequent or complex ventricular arrhythmias (couplets, triplets, or NSVT) seem rare in young competitive athletes (6%–13%).[103-108]

Given these collective findings, a limitation in the current International Criteria is that recommendations for additional testing are based on the quantity of PVCs on a 12-lead ECG without consideration of the PVC morphology. An athlete could have 1 PVC from a concerning origin (eg, LBBB with superior or intermediate axis) and not undergo further evaluation for structural heart disease, whereas another athlete with 2 PVCs of outflow tract or fascicular origin may undergo an extensive workup when underlying disease is unlikely. Future iterations of ECG screening criteria should consider the addition of PVC morphology in some form, and research should assess the combined diagnostic effect of PVC morphology and PVC burden on the surface ECG in the PPCS setting.

ST-Segment Depressions

Current International Criteria recommendations consider an ECG abnormal if there are ST-segment depressions 0.5 mm or greater in 2 or more contiguous leads.[11] ST-depressions are frequently a marker of underlying myocardial disease and can be found in conditions leading to SCD in young competitive athletes such as hypertrophic cardiomyopathy.[109,110] However, the current guidelines do not specifically comment on ST-segment depression morphology (eg, upsloping, horizontal, or downsloping) as a component of this assessment, likely because prior studies in athletes have focused on the presence or absence of ST-segment depressions and have not reported the morphology of the ST changes in detail. Given that ST-segment depressions are generally considered abnormal and possibly associated with pathologic condition in the general population when they are horizontal or downsloping, research is needed to determine if upsloping ST-segment depressions among athletes truly warrants more evaluation or if it could be considered a normal or borderline finding.

Borderline Findings

The International Criteria currently includes a section of “borderline” ECG abnormalities (left atrial enlargement, right atrial enlargement, left axis deviation, right axis deviation, complete RBBB) where 2 or more abnormalities in this category are needed to warrant further testing.[11] The borderline category was created to account for the findings of the seminal study by Gati and colleagues, which demonstrated that athletes with isolated axis deviation or atrial enlargement (n = 579) did not have any major structural or functional abnormalities on TTE.[38] Complete RBBB patterns are also included in the borderline category on the basis of a study of 510 US athletes, which found 2.5% (n = 13) to have a complete RBBB, all of whom were free of pathologic structural heart disease.[111] The authors of this study also subsequently assessed the association of RBBB with pathologic condition from previous athlete studies and found no reported cardiac pathologic condition among asymptomatic athletes with complete RBBB.[112]

Although this group of borderline findings has been a major driver in reducing false-positive interpretations, considerable uncertainty remains regarding whether specific combinations of borderline ECG abnormalities are associated with high-risk conditions or whether certain combinations may actually be considered normal findings. As such, additional research adding granularity to athletes with 2 or more borderline ECG findings would be valuable.

Beat-to-Beat Variation

Although the International Criteria provide a framework for normal and abnormal ECG findings in athletes, a frequently encountered issue not covered in the text is how to handle beat-to-beat variation. When interpreting an athlete's ECG, it is very common that there may be 2 to 3 beats available for each lead that is not included in the rhythm strip. Interpretation of abnormal findings can be difficult if an abnormality is visualized in a subset of the beats available in any specific lead (eg, TWI meets criteria in 1/3 or 2/3 beats). Guidance on how to interpret beat-to-beat variation would be valuable in future iterations of ECG interpretation guidelines. For instance, greater than 50% of the beats in a given lead might be required to define an abnormality as "present." Although published research on this topic is lacking, it seems likely that the proportion of beats with a given finding will have implications for test sensitivity and specificity. For example, if TWI is only required in 1/3 beats to be considered abnormal as opposed to 2/3 or 3/3 beats, this definition may be more sensitive but likely less specific.

SUMMARY

Criteria for the evaluation of the athlete's ECG have evolved considerably during the past 20 years because the scientific understanding of physiologic versus pathologic findings has expanded. With ongoing refinement, metrics of test performance have markedly improved. Nevertheless, important challenges and pitfalls to the application and interpretation of these criteria remain with several important areas of future research identified to fill existing knowledge gaps. Ongoing efforts are required to further refine ECG interpretation standards in athletes.

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CLINICS CARE POINTS

- The International Criteria for ECG interpretation in athletes have improved specificity of ECG interpretation in this population. These can be used as a reference at the point of care by clinicians evaluating athlete ECGs.
- Common pitfalls in athlete ECG interpretation that the clinician should be aware of include identification of pathologic inferior T-wave inversions and pathologic Q waves, recognition of the black athlete repolarization pattern, and correct application of the criteria's 'borderline' finding category.
- Normative ECG data specific to the sport and population in question are required, and caution should be exercised applying data from different populations and athletic contexts.
- Other areas requiring additional research include the significance of low QRS voltage and QRS fragmentation, greater granularity regarding the implications of specific PVC morphologies, and more specific guidance regarding beat-to-beat variation in ECG findings.

KEY POINTS

- The International Criteria for electrocardiogram (ECG) interpretation is the current standard of care for preparticipation ECG screening in young competitive athletes.
- Common pitfalls using the International Criteria include incorrect interpretation of inferior T-wave inversions, black athlete repolarization patterns, pathologic Q waves, and borderline ECG criteria.
- Future directions to consider for new ECG screening criteria include expanding age/sex/geographic origin-specific ECG changes, addressing low QRS voltage criteria and QRS fragmentation, defining nuanced preventricular contraction (PVC) and ST-segment depression morphology, and providing interpretation guidance when beat-to-beat variation is present.

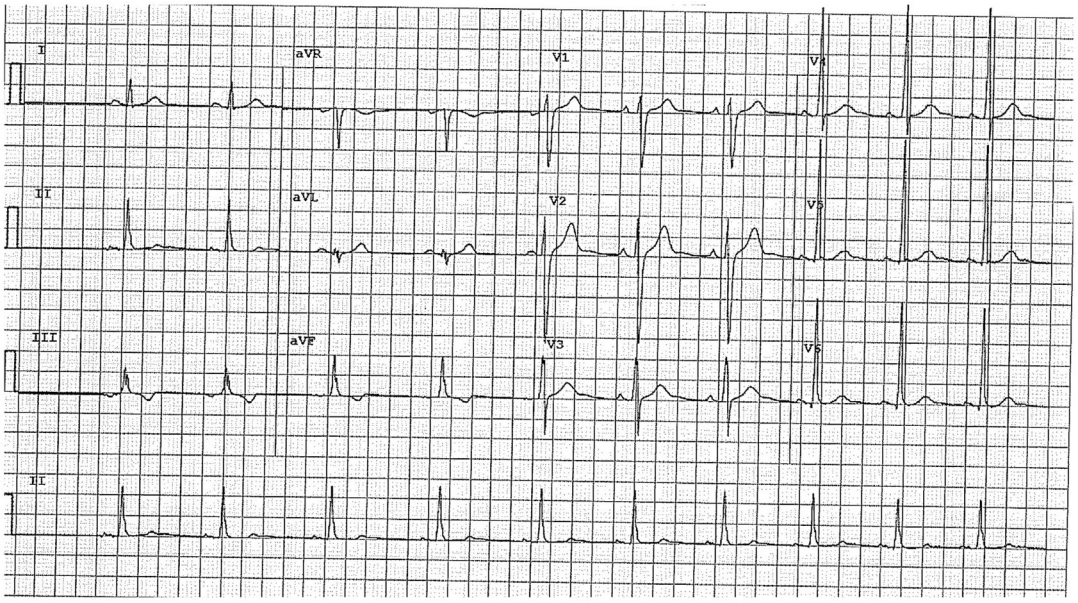

Fig. 1.

Common Pitfalls—Inferior TWIs. Example of an ECG with isolated inferior TWIs in leads III and aVF. This ECG is considered normal per the International criteria. Given TWI in III is considered normal, inferior TWI need to be present in both II and aVF to be considered abnormal.

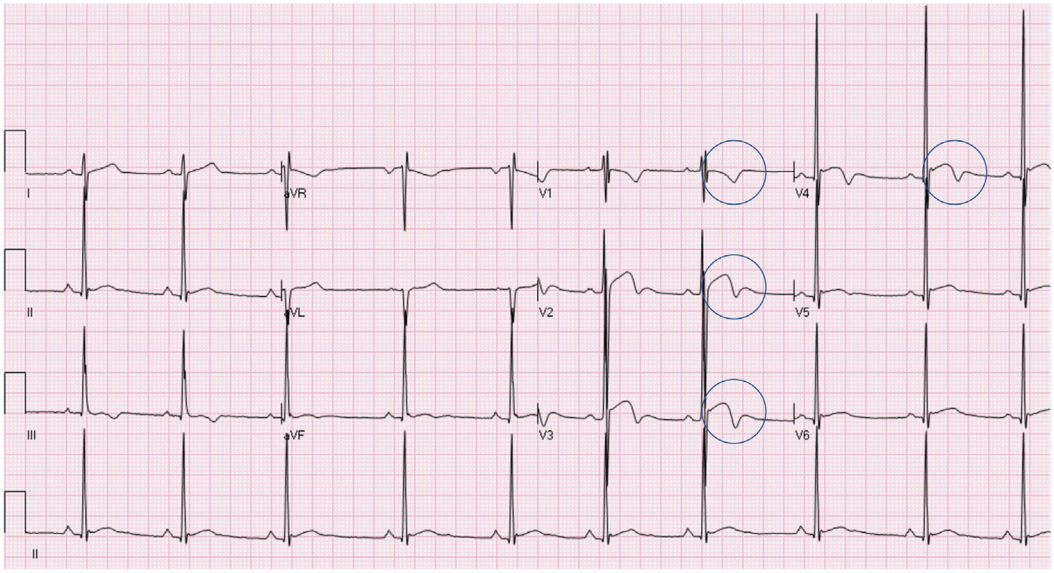

Fig. 2.

Common Pitfalls—Black athlete repolarization pattern. Example of an ECG with a Black athlete repolarization pattern (J point elevation with convex ST elevation and TWIs confined to V1–V4—denoted here with *blue circles*). This ECG is considered normal per the International Criteria. TWIs extending into V5 are always considered abnormal.

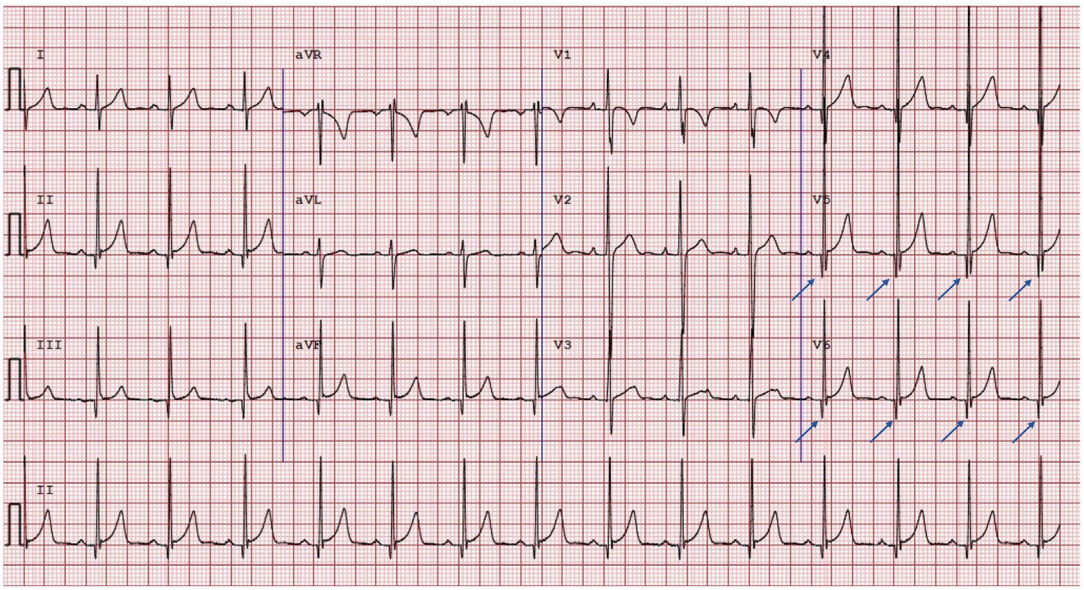

Fig. 3.

Common Pitfalls—Nonpathologic Q waves. Example of an ECG with Q waves greater than 3 mm in the lateral leads (*blue arrows*). This ECG is normal per the International Criteria, given the International Criteria requires Q/R ratio of 0.25 or greater or q of 40 milliseconds or greater in 2 or more leads (excluding III and aVR).

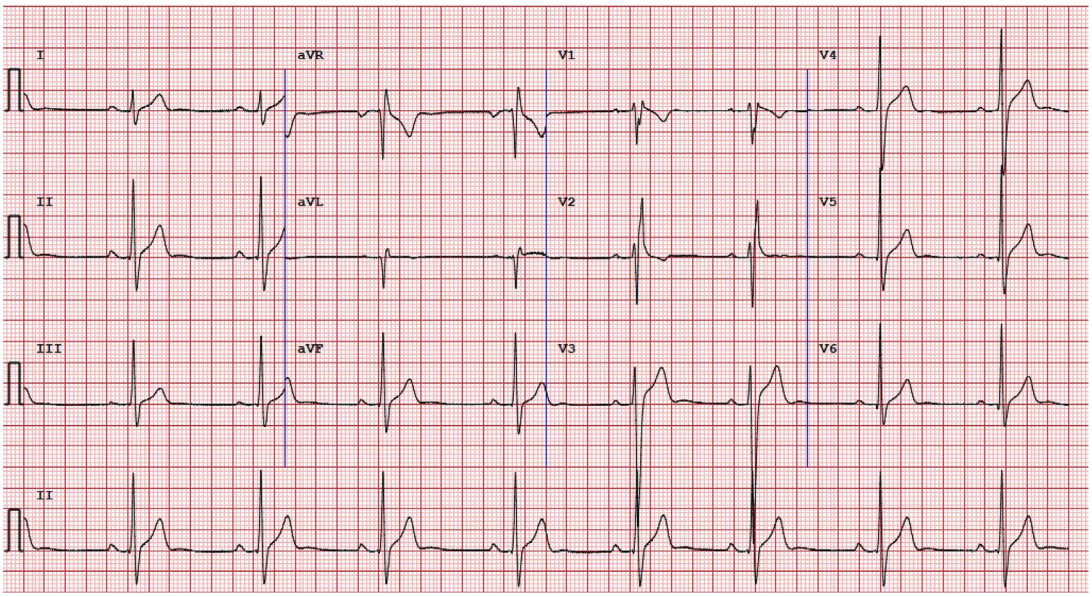

Fig. 4.

Common Pitfalls—Isolated right bundle branch block. Example of ECG with isolated complete right bundle branch block. QRS axis does not meet International Criteria threshold for right axis deviation (≥120°). This ECG would be considered as normal per the International Criteria given that only one borderline criteria is present and there are no other abnormal findings.

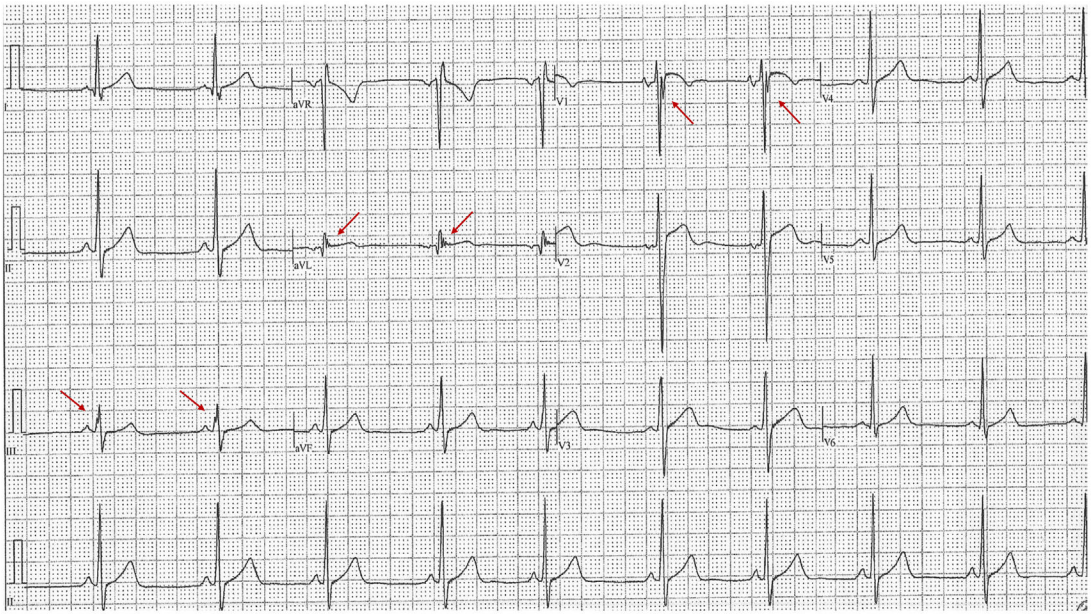

Fig. 5..

QRS fragmentation. Example of ECG with QRS fragmentation. Red arrows indicate examples of QRS fragmentation.

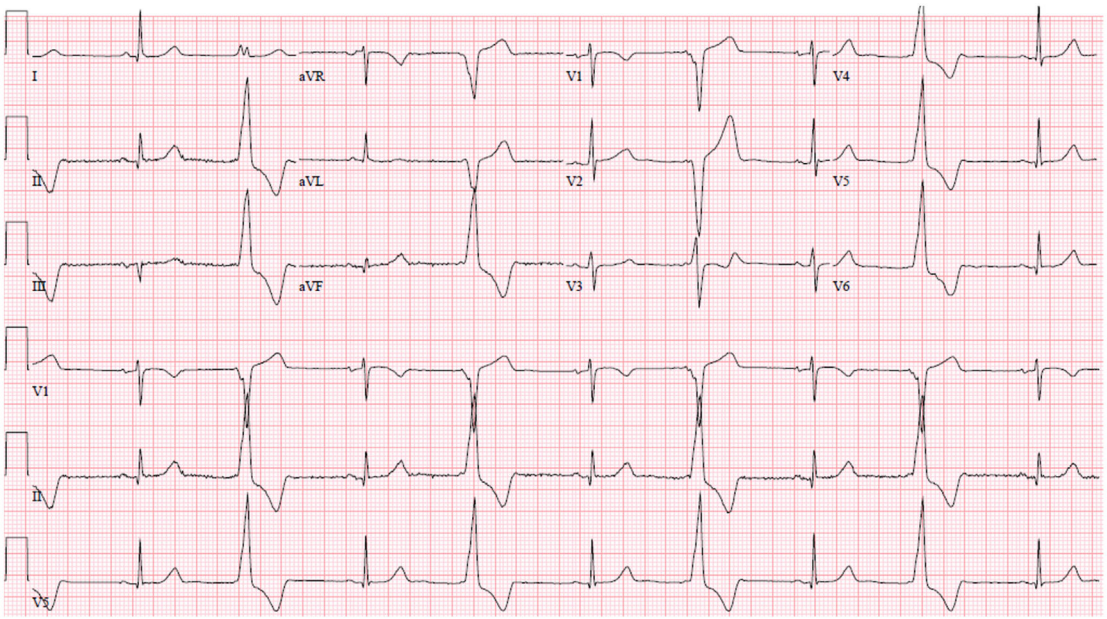

Fig. 6.

RVOT PVCs. Example of ECG with RVOT PVCs. Pertinent features include left bundle branch block pattern, inferior axis, and late precordial transition. RVOTs are broadly considered more likely to have a benign course.

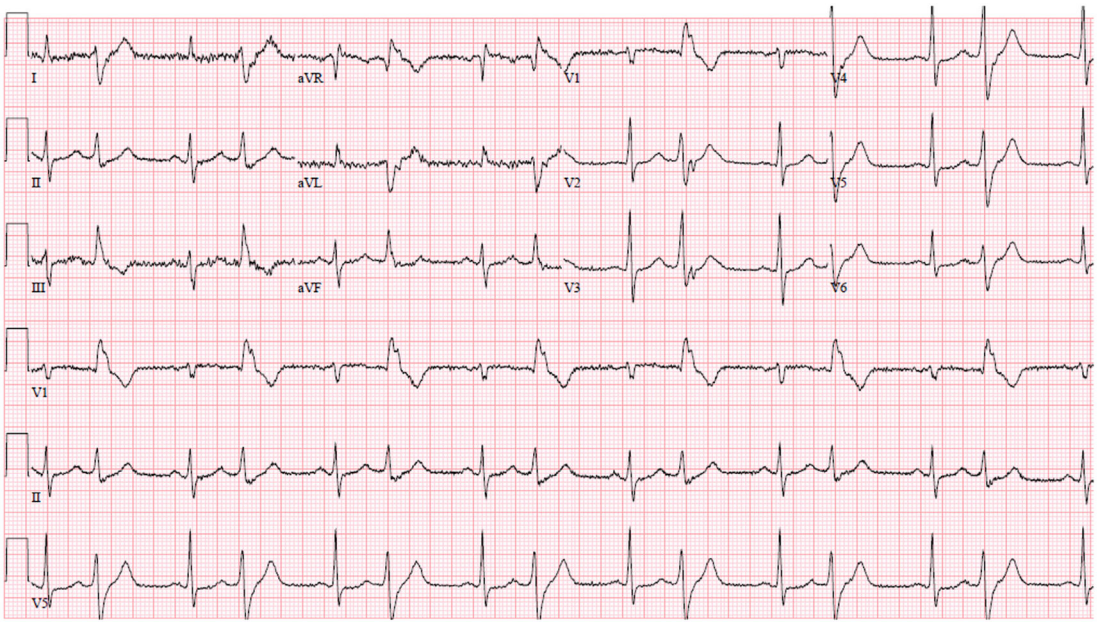

Fig. 7..

Papillary muscle PVCs. Example of ECG with PVCs originating from papillary muscle. Note the atypical right bundle branch block pattern with wide (≥130 milliseconds) QRS. This PVC morphology is more often associated with myocardial disease and increased risk for malignant clinical course.

Table 1

Common pitfalls of electrocardiogram interpretation in athletes using the International Criteria

ECG Abnormality	Common Pitfalls
Inferior TWI	Classified as abnormal with TWI in lead III plus aVF or lead II. Per the International Criteria, TWI in lead III is not considered abnormal; thus, abnormal inferior TWI requires TWI in both lead II and aVF (Fig. 1)
Black athlete repolarization pattern	ECGs are classified as abnormal, which have a physiologic Black athlete repolarization pattern consisting of J-point elevation with convex ST-segment elevation and TWI confined to V1–V4 (Fig. 2). Extension of TWI into V5 is an abnormal finding and not part of the Black athlete repolarization pattern
Pathologic Q waves	Classified as abnormal when the Q wave is long and thin but does not meet newer criteria including a Q/R > 0.25 or Q wave >40 ms duration (Fig. 3)
Borderline ECG findings	Athletes with 1 borderline ECG finding (eg, axis deviation, atrial enlargement, or complete RBBB) are flagged as abnormal when the International Criteria requires 2 borderline findings (Fig. 4)

Table 2.

Future directions of electrocardiogram interpretation in athletes

ECG Parameters	Future Considerations
Age/sex/geographic origin	Optimization of ECG criteria in diverse populations
PVC morphology	Consideration of the frequency of PVCs in conjunction with PVC morphology as “benign” or “malignant” (eg, 1 malignant PVC vs multiple benign PVCs warrants additional investigation)
Low QRS voltage	Consideration of adding low QRS voltage criteria given association with ARVC, myocarditis, nonischemic LV scar, and infiltrative myocardial diseases
QRS fragmentation	Consideration of QRS fragmentation as a potential borderline finding because this parameter has been associated with multiple pathologic cardiovascular conditions in the general population
ST-segment depression morphology	Consideration of ST-segment depression morphology (eg, horizontal or downsloping [but not upsloping] warrants additional investigation)
Borderline ECG findings	Further understanding on which combination of findings predict underlying pathologic condition
Beat-to-beat variation	Guidance on how to interpret abnormal ECG findings if only present in a subset of beats in any specific lead (eg, abnormal if >50% of beats)