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Research paper

Athlete ECG T-wave abnormality interpretation patterns by non-experts

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ABSTRACT

Background: The presence of T-wave abnormalities (TWA) on an athlete's electrocardiogram (ECG) presents as a diagnostic challenge for physicians. Types of TWA patterns classified as abnormal by inexperienced readers have not been systematically analyzed.
Methods: ECGs from the 2011–2015 National Football League Scouting Combine (initially interpreted by general cardiologists) were retrospectively reviewed by expert sports cardiologists with strict application of the 2017 International Criteria. Patterns of TWA that were altered from the original interpretation were analyzed.
Results: The study included 1643 athletes (mean age 22 years). There was a 67 % reduction in the number of athletes with any TWA ($p < 0.001$) with 111 ECGs changed to normal. Inferior TWA was the most common interpreted initial ECG abnormality altered followed by anterior and lateral.
Discussion: This analysis revealed an initial high rate of TWA by non-expert readers. Tailored education programs to physicians who interpret athlete ECGs should highlight these specific T-wave patterns. We see this as an opportunity to make more clinicians aware of ECG interpretation guidelines as sports trained cardiologists are mostly self-taught.

1. Introduction

Accurate ECG interpretation in athletes is important in identifying a young person with an underlying cardiovascular disease that potentially places them at increased risk of sudden cardiac death, but to also limit false positives which results in extraneous downstream testing and athlete/family anxiety. This process can be challenging for the practicing physician as there are multiple patterns seen in young athletes that would be considered abnormal in the sicker and older adult population for which most physicians are trained. Interpretations of athlete ECGs by inexperienced readers without the use of specific criteria have been demonstrated [1,2]; however, prior studies have been less specific about which patterns tend to create the most problems for inexperienced readers. The presence of T-wave abnormalities (TWA) in athletes can range from associations with early signs of cardiac remodeling to concealed underlying structural heart disease. While standardized criteria have helped practicing physicians [3], interpretation of TWA can still be difficult [4]. We hypothesized that inferior, anterior, and lateral lead TWA patterns would be the most problematic for inexperienced readers interpreting athlete ECGs as TWA in these leads have very specific definitions in published athlete specific ECG interpretation criteria that differ from traditional adult ECG criteria.

2. Methods

Standard 12-lead ECGs from 2011 to 2015 were retrieved from the NFL Scouting Combine database (MUSE Versions 7 and 8, GE Healthcare, Wauwatosa, WI) at Indiana University Health. The study was deemed exempt from IRB review by Kuali Coeus ® IRB Office of Research Compliance from Indiana University. Original ECG

Abbreviations: ECG, electrocardiogram; TWA, T-wave abnormality; IC, International Criteria.

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interpretations were categorized as *Normal*, *Borderline*, or *Abnormal* using standard GE MUSE™ reporting system at the time the athlete was initially evaluated upon participation in the NFL Scouting Combine. MUSE™ is a database managing system for ECGs that uses a vendor specific proprietary ECG analysis algorithm for ECG analysis and is one of the most popular systems used in health systems. The reporting system algorithmic generated preliminary interpretation was confirmed or altered by the original interpreting physician at their discretion. There were on average 3 readers per year, and all had training in general cardiology but were not experts in sports cardiology. Formal athlete ECG interpretation standards were evolving over the study period and available to the original interpreting physician; however, interpretation was at their own discretion without specific recommendations. ECGs were retrospectively over-read and interpreted as *Normal* or *Abnormal* by a sports cardiologist (M.S.E) using the International Criteria (IC) which were published in 2017 [5]. TWA criteria and definitions per IC are outlined in Table 1. All ECGs with TWA changed from the initial read were subsequently reviewed by a second experienced sports cardiologist (M.W.M) to adjudicate the final classification. M.S.E and M.W.M were only involved in the over-read and not involved in the initial reading process. TWA patterns that were either altered or reclassified were recorded. Proportions of TWA findings that were changed using the IC was assessed using McNemar's test and chi-square testing. All analyses were performed using R version 3.6.3 software (R Foundation for Statistical Computing, Vienna, Austria). A 2-tailed p-value <0.05 was considered statistically significant.

3. Results

There were 1643 athletes in this cohort and all males. Race was self-reported as 1112 (68 %) Black, 402 (24 %) white, and the remaining 129 (8 %) were of other races/ethnicities. The mean age was 22 years (18–31 years) and the mean BMI was 31 kg/m^2 (21.7–44.3).

There was a 67 % reduction in the number of athletes with any TWA ($p < 0.001$) with 111 total ECGs changed to *Normal* because of TWA reclassification. After the over-read, there was 78 % relative reduction in inferior TWI ($p < 0.001$), 12 % relative reduction in lateral TWA ($p = 0.020$), and an 86 % relative reduction in anterior TWA ($p < 0.001$) (Fig. 1). Of the initial 47 anterior TWA classified as *Abnormal*, 30 (64 %) were reclassified as *Normal* consistent with typical anterior Black athlete pattern. There was no significant trend over the 5-year study period for TWA interpretation patterns as classified by the original readers ($p = 0.66$) which was similar for inferior ($p = 0.09$), lateral ($p = 0.50$), and anterior TWA ($p = 0.99$).

4. Discussion

The detection of TWA should always be viewed as pathological warranting further testing because it may represent the initial expression of a cardiomyopathic process potentially placing the athlete at risk of sudden cardiac death. While the incidence of sudden cardiac death in athletes is relatively low (1 in 40,000-80,000) [6], these cases are tragic and often highly public events. While TWA is a finding that warrants further scrutiny, there remains the valid concern of false positive interpretations from improper application of published interpretation standards in this unique population.

In our study, inferior TWAs were commonly misclassified as abnormal during the initial interpretations either because of inclusion of lead III (Fig. 2A) or the depth of the TWI was not ≥1 mm (Fig. 2B). Contemporary criteria for interpretation of ECGs in athletes exclude leads V1, III and aVR, and as such define inferior TWA by contiguous T-wave inversions using leads II AND aVF only [5,7].

Interpretation of lateral TWA was not as problematic but those that were misclassified were primarily due to interpretation of the depth of the T-waves (Fig. 2C and D). The IC classify lateral TWA with T-wave inversion ≥ 2 mm as abnormal utilizing lead I and aVL, V5 and/or V6 (only one lead of TWI required in V5 or V6).

Anterior TWA were primarily misclassified because of the interpretation of the Black athlete pattern (Fig. 2E), but also because of interpretation of biphasic T-waves in lead V3 and TWA isolated to leads V1 and V2. Anterior TWA are defined as T-wave inversions beyond lead V2 in non-Black athletes. The physiologic Black athlete pattern is defined as J-point elevation with convex ST segment elevation followed by TWI isolated to leads V2-V4. There were only 7 (0.4 %) anterior TWA in this cohort using the IC and 30 athletes with the Black athlete pattern. 62 % of anterior TWAs changed were a result of the Black athlete pattern. The Seattle and Refined criteria made it clearer that this anterior T-wave pattern in athletes of African/Caribbean descent was considered a normal variant which continued into the IC.

The root of the problem is that athlete ECG interpretation criteria differ from traditional criteria taught for interpretation of ECGs in general medical training programs and those incorporated into computer interpretation algorithms utilized in health systems. The influence of computer-generated interpretations cannot be ascertained from these data but may have influenced the original interpreter's final classification [8,9].

A notable limitation to our study was that the specific standardized ECG interpretation criteria used by the initial readers could not be ascertained. Additionally, the intent and design of this study did not include additional testing (e.g., transthoracic echocardiography) that may have been performed on the athletes because of their ECG patterns. Another limitation is that while the over-read of ECGs was performed using the IC, the IC were not published at the time of original ECG interpretation and this could have impacted how many ECGs were changed. This study included only ECGs of young, primarily Black male athletes participating in American style football players and may not reflect patterns for different sport types, races/ethnicities, or in older cohorts.

In summary, our findings demonstrate the interpretation of TWA by less experienced readers not adhering to strict ECG standard guidelines result in a relatively high rate of abnormal ECG interpretations. With every new iteration of athlete ECG interpretation guidelines, ECG interpretation has become much more specific resulting in a marked reduction in false positives. A lack of properly trained and experienced sports cardiologists makes it even more imperative to properly educate physicians to identify true pathological TWA. Future initiatives aimed at all levels of experience to improve physician education in ECG and in particular T-wave interpretation should highlight the patterns we have identified and be included in comprehensive training programs. Promoting online training modules and athlete workshops for pediatricians, primary care physicians, sports medicine physicians and cardiologists who care for athletes may be one way to achieve those goals.

Table 1
International consensus standards for ECG interpretation in athletes: definitions of T-wave abnormalities [5].

T wave inversion	Definition: ≥1 mm in depth in two or more contiguous leads (excludes leads aVR, III and V1)
Anterior	V2-V4 Excludes: black athletes with J-point elevation and convex ST segment elevation followed by TWI in V2-V4; athletes < age 16 with TWI in V1-V3; and biphasic T waves in only V3
Lateral	I and aVL, V5 and/or V6 (only one lead of TWI required in V5 or V6)
Inferior	II and aVF

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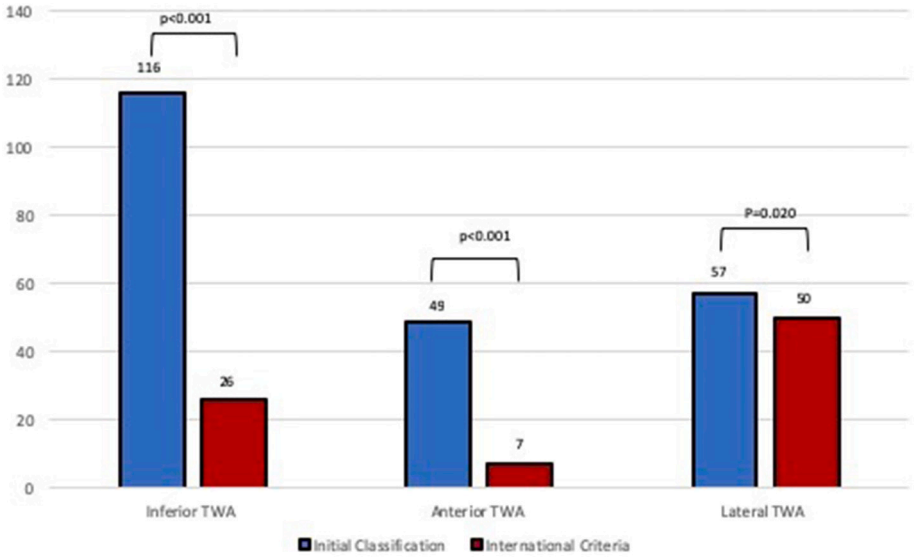

Fig. 1. Number of T-wave abnormalities (TWA) noted by initial non-expert readers and by expert overread utilizing the International Criteria for electrocardiographic interpretation in athletes.

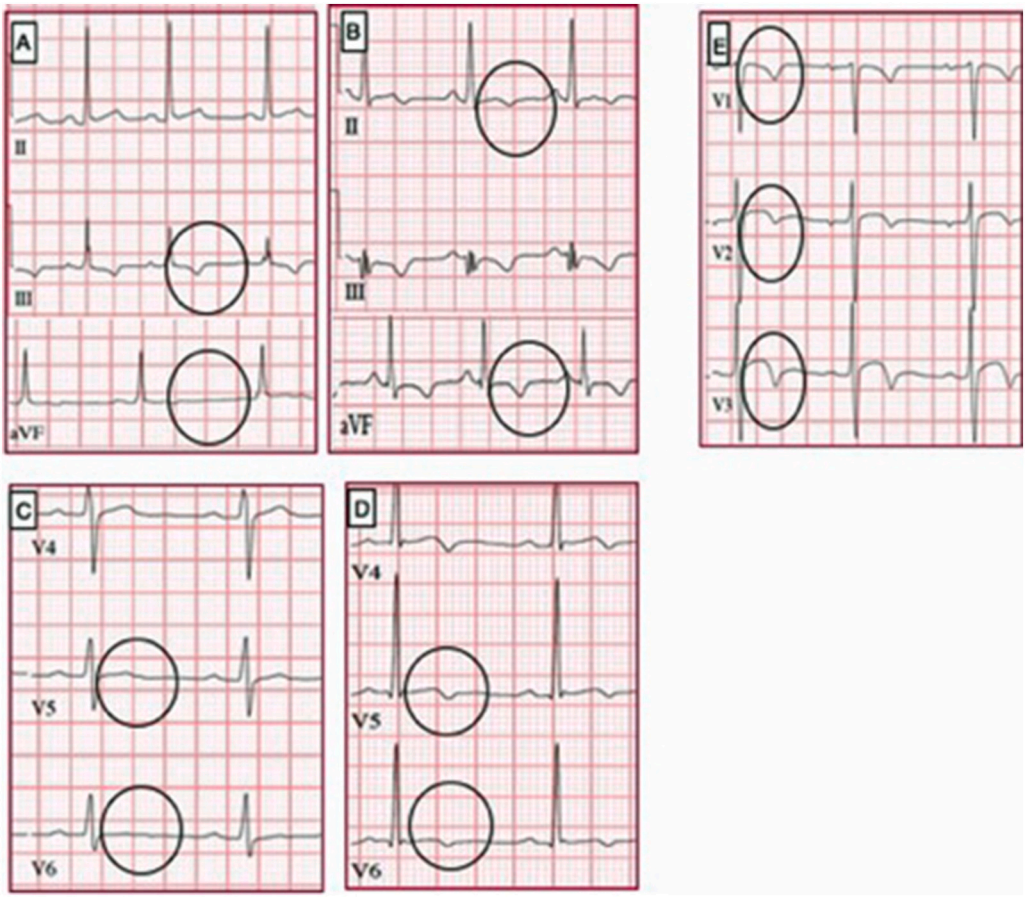

Fig. 2. Common T-wave patterns noted by initial non-expert readers reclassified by expert overread utilizing the International Criteria (IC) for electrocardiographic interpretation in athletes.
Panel A demonstrates T-wave inversion in III and flattening in aVF (circles) originally classified as abnormal and reclassified as normal by International Criteria (IC).
Panel B demonstrates T-wave inversions in II and aVF (circles) which are abnormal. IC excludes lead III in the interpretation of T-wave abnormalities.
Panel C demonstrates T-wave flattening (circles) originally classified as abnormal which are not considered as abnormal by the IC.
Panel D demonstrates T-wave inversions in V5 and V6 (circles) which are considered abnormal by the IC.
Panel E shows an ECG from a Black athlete with convex ST segment elevation followed by T-wave inversion in V1-V3 (circles) originally classified as abnormal. The IC considered this a normal repolarization pattern in Black athletes.

Ethics approval

The study was deemed exempt from IRB review by Kuali Coeus ® IRB Office of Research Compliance. Consent form was not required as data are completely anonymous.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] B.J. Petek, J.A. Drezner, J.M. Prutkin, D.S. Owens, T. Tran, K.G. Harmon, Electrocardiogram interpretation in college athletes: local institution versus sports cardiology center interpretation, J. Electrocardiol. 62 (2020) 49–56.
[2] M. Weiss, P. Rao, D. Johnson, T. Billups, C. Taing, M. LaNoue, et al., Physician adherence to 'Seattle' and 'International' ECG criteria in adolescent athletes: an analysis of compliance by specialty, experience, and practice environment, J. Electrocardiol. 60 (2020) 98–101.
[3] J.A. Drezner, I.M. Asif, D.S. Owens, J.M. Prutkin, J.C. Salerno, R. Fean, et al., Accuracy of ECG interpretation in competitive athletes: the impact of using standised ECG criteria, Br. J. Sports Med. 46 (5) (2012) 335–340.
[4] F. D'Ascenzi, F. Anselmi, P.E. Adami, A. Pelliccia, Interpretation of T-wave inversion in physiological and pathological conditions: current state and future perspectives, Clin. Cardiol. 43 (8) (2020) 827–833.
[5] J.A. Drezner, S. Sharma, A. Baggish, M. Papadakis, M.G. Wilson, J.M. Prutkin, et al., International criteria for electrocardiographic interpretation in athletes: consensus statement, Br. J. Sports Med. 51 (9) (2017) 704–731.
[6] M.S. Emery, R.J. Kovacs, Sudden cardiac death in athletes, JACC Heart failure 6 (1) (2018) 30–40.
[7] J.A. Drezner, M.J. Ackerman, J. Anderson, E. Ashley, C.A. Asplund, A.L. Baggish, et al., Electrocardiographic interpretation in athletes: the 'Seattle criteria', Br. J. Sports Med. 47 (3) (2013) 122–124.
[8] J. Schläpfer, H.J. Wellens, Computer-interpreted electrocardiograms: benefits and limitations, J. Am. Coll. Cardiol. 70 (9) (2017) 1183–1192.
[9] T. Novotny, R. Bond, I. Andrsova, L. Koc, M. Sisakova, D. Finlay, et al., The role of computerized diagnostic proposals in the interpretation of the 12-lead electrocardiogram by cardiology and non-cardiology fellows, Int. J. Med. Inform. 101 (2017) 85–92.