

The Athletes EKG: Pitfalls in Interpretation



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Financial Disclosures

Affiliations:



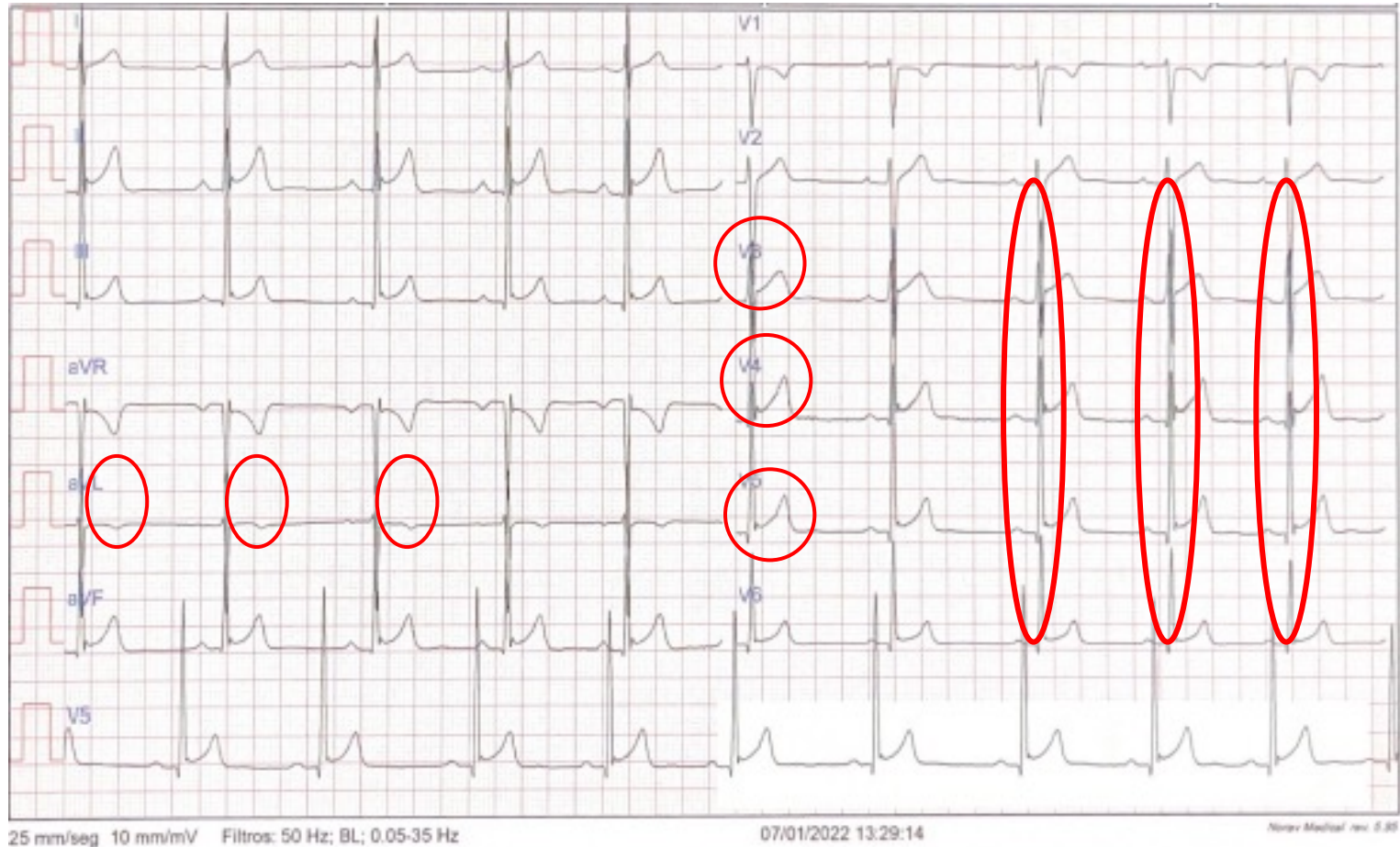
Funding Sources:

- National Institutes of Health
- American Heart Association
- American Society of Echocardiography
- Department of Defense
- National Football League Player's Association
- American Medical Society for Sports Medicine

Opening Thoughts

“Hi Dr. Baggish, Dr. X and I just received this ECG and we’re concerned about the:”

1. Massive LVH
2. The T-wave inversion in aVL
3. The anteroseptal acute MI pattern



Learning Objectives

Indeed, the “Athlete’s ECG” can be dramatic.....

Practical Considerations about the 12-lead ECG

✓ **Technique** matters, first thing to consider is whether finding is a technical issue

Pre-test probability defines response to findings

ECG’s in isolation are of limited value ≠ CLEARANCE

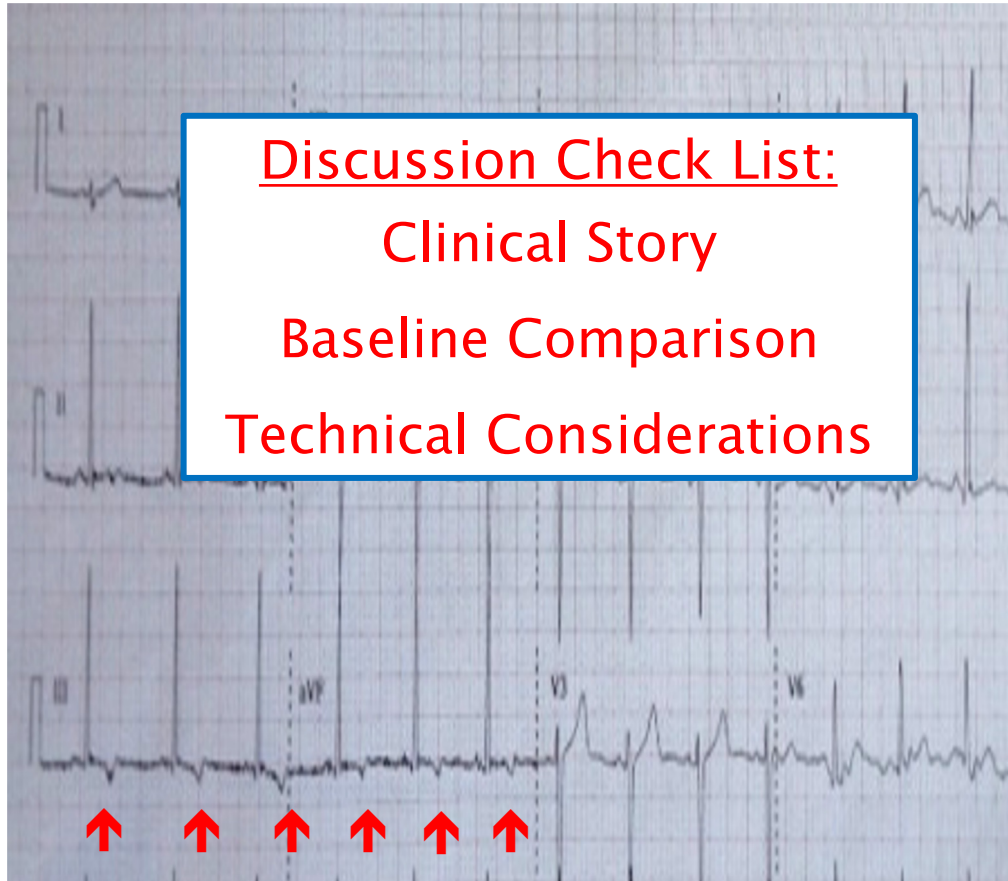
Diagnostic Criteria have been developed to help with this process

Consistency is key and requires repetition and systematic approach

ECG: Technical Considerations

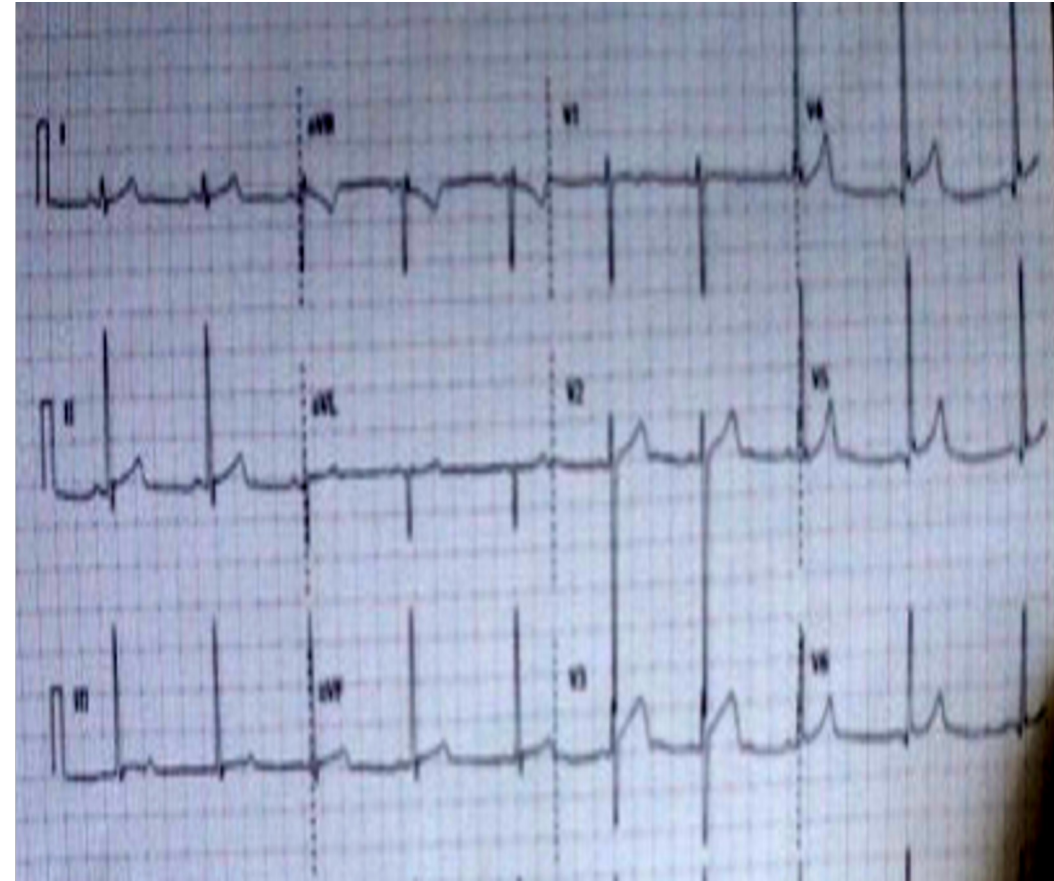
19 y.o.M distance runner with
allergies and chest tightness
(Training Room #1)

Seated Tracing



19 y.o.M distance runner with
allergies and chest tightness
(Training Room #2)

Supine Tracing



ECG: Technical Considerations

Resting Physiology



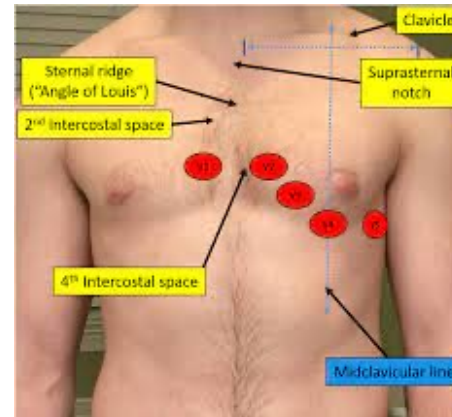
Baseline Comparator



Patient Position



Lead Placement



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Pre-participation Screening



1. Personal history

- Syncope or near-syncope
- Exertional chest pain or discomfort
- Shortness of breath or fatigue out of proportion to the degree of physical effort
- Palpitations or irregular heartbeat

Resting symptoms have low specificity of pathology

The majority of “yes” response do not indicate true disease (low specificity)

Real-time follow-up determine need for further evaluation

Pre-participation Screening

1. Personal history

- Syncope or near-syncope



vs.



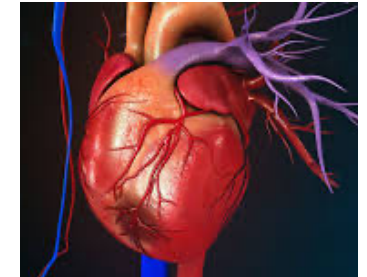
Neurally-Mediated (Rest ~10%)
Post-Exercise Collapse (2-5%)

Arrhythmogenic
Syncope

- Exertional chest pain or discomfort

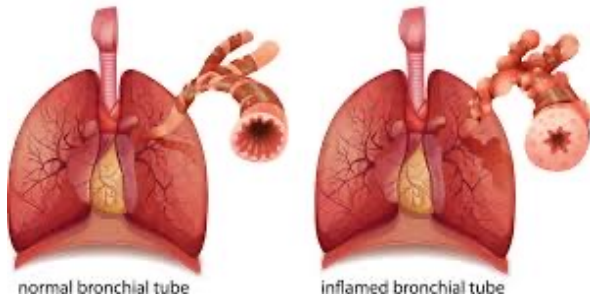


vs.

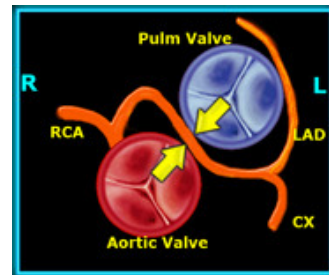


- Shortness of breath or fatigue
out of proportion to the degree of physical effort

Asthma - Inflamed Bronchial Tube



vs.



- Palpitations or irregular heartbeat



vs.



If you know and practice the nuanced follow-up, the specificity of H&P improves

Pre-participation Screening



2. Family history

- Family history of one or more relatives with disability or death of heart disease (sudden/unexpected) before age 50
- Family history of cardiomyopathy, coronary artery disease, Marfan syndrome, long QT syndrome, severe arrhythmias, or other disabling cardiovascular disease.

A good family history is worth it's weight in gold!
Take the time to do it well...

Ask about: unexplained drownings & car crashes, sport restriction, early life ICDs

Use the names of the common diseases:
HCM, AVC, Long QT Syndrome, Aortic Dissection, etc.

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✓ **Pre-test probability** defines response to findings

✓ **ECG’s in isolation** are of limited value ≠ CLEARANCE

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Consistency is key and requires repetition and systematic approach

The ECG in Isolation

Elite Level Competitor

Long Standing Med-Refractory Asthma

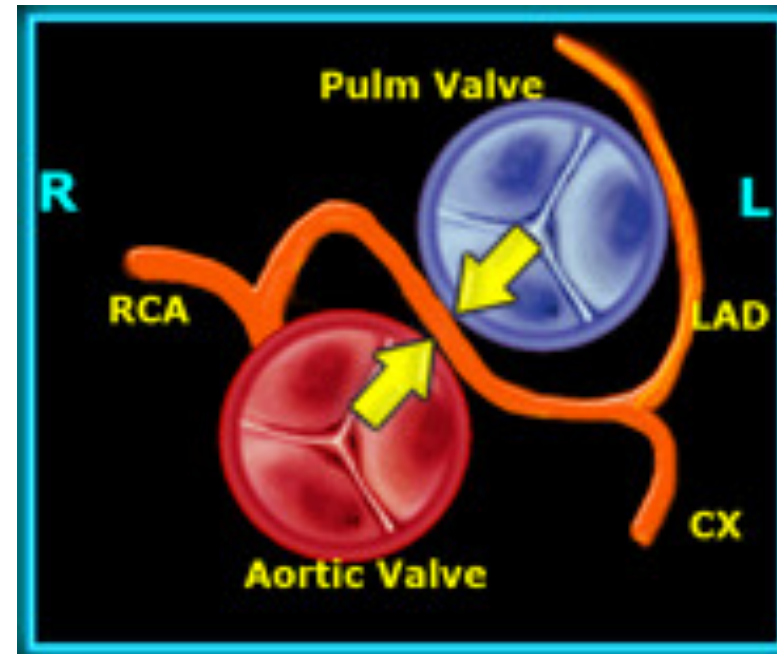
Normal Screening ECG



February 2014

Sudden Cardiac Death

50K - Craftsbury VT



Indeed, the “Athlete’s ECG” can be dramatic.....

Practical Considerations about the 12-lead ECG

- ✓ **Technique** matters, first thing to consider is whether finding is a technical issue
 - ✓ **Pre-test probability** defines response to findings
 - ✓ **ECG’s in isolation** are of limited value ≠ CLEARANCE
- ✓ **Diagnostic Criteria** have been developed to help with this process
- Consistency** is key and requires repetition and systematic approach

ECG Criteria: *The Evolution*

Criteria (O.E.D.): A list of principles or standards by which something may be judged or decided

-Ubiquitous in medicine & science....**Appropriate Use** Criteria (A.U.C.)

-Provide **standardization** across time, space, and level of expertise

-**Starting point** for diagnostic decision making

-They are imperfect and only as good as the **data** & **experience** that generate them

ABSTRACT

Background For more than 20 years in Italy, young athletes have been screened before participating in competitive sports. We assessed whether this strategy results in the prevention of sudden death from hypertrophic cardiomyopathy, a common cardiovascular cause of death in young athletes.

Methods We prospectively studied sudden deaths among athletes and nonathletes (35 years of age or less) in the Veneto region of Italy from 1979 to 1996. The causes of sudden death in both populations were compared, and the pathological findings in the athletes were related to their clinical histories and electrocardiograms. Cardiovascular reasons for disqualification from participation in sports were investigated and follow-up was performed in a consecutive series of 33,735 young athletes who underwent preparticipation screening in Padua, Italy, during the same period.

Results Of 269 sudden deaths in young people, 49 occurred in competitive athletes (44 male and 5 female athletes; mean [\pm SD] age, 23 \pm 7 years). The most common causes of sudden death in athletes were arrhythmogenic right ventricular cardiomyopathy (22.4 percent), coronary atherosclerosis (18.4 percent), and anomalous origin of a coronary artery (12.2 percent). Hypertrophic cardiomyopathy caused only 1 sudden death among the athletes (2.0 percent) but caused 16 sudden deaths in the nonathletes (7.3 percent). Hypertrophic cardiomyopathy was detected in 22 athletes (0.07 percent) at preparticipation screening and accounted for 3.5 percent of the cardiovascular reasons for disqualification. None of the disqualified athletes with hypertrophic cardiomyopathy died during a mean follow-up period of 8.2 \pm 5 years.

Conclusions The results show that hypertrophic cardiomyopathy was an uncommon cause of death in these young competitive athletes and suggest that the identification and disqualification of affected athletes at screening before participation in competitive sports may have prevented sudden death. (N Engl J Med 1998;339:364-9.)

©1998, Massachusetts Medical Society.

The New England Journal of Medicine

(N Engl J Med 1998;339:364-9.)

SCREENING FOR HYPERTROPHIC CARDIOMYOPATHY IN YOUNG ATHLETES

DOMENICO CORRADO, M.D., CRISTINA BASSO, M.D., MAURIZIO SCHIAVON, M.D., AND GAETANO THIENE, M.D.

TABLE 4. CARDIOVASCULAR CONDITIONS CAUSING DISQUALIFICATION FROM COMPETITIVE SPORTS IN 621 ATHLETES IN PADUA, 1979 TO 1996.

CONDITION	No. (%)
Rhythm and conduction abnormalities	238 (38.3)
Systemic hypertension	168 (27.1)
Valvular diseases (including mitral-valve prolapse)	133 (21.4)
Hypertrophic cardiomyopathy	22 (3.5)
Others	60 (9.7)

TABLE 1. CRITERIA FOR A POSITIVE 12-LEAD ELECTROCARDIOGRAM.*

P wave

Left atrial enlargement: negative portion of the P wave in lead V₁ \geq 0.1 mV in depth and \geq 0.04 sec in duration

Right atrial enlargement: peaked P wave in leads II and III or V₁ \geq 0.25 mV in amplitude

QRS complex

Frontal-plane axis deviation: right \geq +120 degrees or left -30 degrees to -90 degrees

Increased voltage: amplitude of R or S wave in a standard lead \geq 2 mV, S wave in lead V₁ or V₂ \geq 3 mV, or R wave in lead V₅ or V₆ \geq 3 mV

Abnormal Q waves \geq 0.04 sec in duration or \geq 25 percent of the height of the ensuing R wave, or QS pattern in two or more leads

Right or left bundle-branch block with QRS duration \geq 0.12 sec
R or R' wave in lead V₁ \geq 0.5 mV in amplitude and R:S ratio \geq 1

ST segment, T waves, and QT interval

ST-segment depression or T-wave flattening or inversion in two or more leads

Prolongation of QT interval corrected for the heart rate >0.44 sec

Rhythm and conduction abnormalities

Premature ventricular beats or more severe ventricular arrhythmia

Supraventricular tachycardia, atrial flutter, or atrial fibrillation

Short PR interval (<0.12 sec) with or without delta wave

Sinus bradycardia with resting heart rate \leq 40 beats per minute and increasing to <100 beats per minute during limited exercise testing

First-degree (PR \geq 0.21 sec, not shortening with hyperventilation or limited exercise testing), second-degree, or third-degree atrioventricular block

*The criteria are from Friedman,¹⁷ Romhilt and Estes,¹⁸ Morris et al.,¹⁹ and Savage et al.²⁰

ESC Report

Cardiovascular pre-participation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol

Consensus Statement of the Study Group of Sport Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology

Domenico Corrado^{1*}, Antonio Pelliccia², Hans Halvor Bjørnstad³, Luc Vanhees⁴, Alessandro Biffi², Mats Borjesson⁵, Nicole Panhuyzen-Goedkoop⁶, Asterios Deligiannis⁷, Erik Solberg⁸, Dorian Dugmore⁹, Klaus P. Mellwig¹⁰, Deodato Assanelli¹¹, Pietro Delise¹², Frank van-Buuren¹⁰, Aris Anastasakis¹³, Hein Heidbuchel⁴, Ellen Hoffmann¹⁴, Robert Fagard⁴, Silvia G. Priori¹⁵, Cristina Basso¹⁹, Eloisa Arbustini¹⁶, Carina Blomstrom-Lundqvist¹⁷, William J. McKenna¹⁸, and Gaetano Thiene¹⁹

¹ Department of Cardiology, University of Padova, Italy

² Institute for Sports Sciences, Rome, Italy

³ Department of Heart Disease, Haukeland University Hospital, Bergen, Norway

⁴ Cardiovascular Rehabilitation Unit, KU Leuven, Leuven, Belgium

⁵ Department of Medicine, Sahlgrenska University Hospital, Östra, Gothenburg, Sweden

⁶ Department of Cardiology, Radboud University, Nijmegen, The Netherlands

⁷ Sports Medicine, Aristotle University, Thessaloniki, Greece

⁸ Klinikk Ullevål Sykehus, Oslo, Norway

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¹¹ Department of Cardiology, University of Brescia, Italy

¹² Civil Hospital, Conegliano, Italy

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¹⁴ Department of Cardiology, University Hospital, Munich, Germany

¹⁵ Molecular Cardiology, Fondazione S. Maugeri, Pavia, Italy

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¹⁷ Department of Cardiology, University Hospital Uppsala, Sweden

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¹⁹ Pathological Anatomy, University of Padova, Italy

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See page 428 for the editorial comment on this article (doi:10.1093/eurheartj/ehi154)

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potential of preventing fatal events. The main purpose of the consensus document is to reinforce the principle of the need for pre-participation medical clearance of all young athletes involved in organized sports programmes, on the basis of (i) the proven efficacy of systematic screening by 12-lead ECG (in addition to history and physical examination) to identify hypertrophic cardiomyopathy—the leading cause of sports-related sudden death—and to prevent athletic field fatalities; (ii) the potential screening ability in detecting other lethal cardiovascular diseases presenting with ECG abnormalities. The consensus document recommends the implementation of a common European screening protocol essentially based on 12-lead ECG.

Table 3 Criteria for a positive 12-lead ECG

P wave

left atrial enlargement: negative portion of the P wave in lead V1 ≥ 0.1 mV in depth and ≥ 0.04 s in duration; right atrial enlargement: peaked P wave in leads II and III or V1 ≥ 0.25 mV in amplitude.

QRS complex

frontal plane axis deviation: right $\geq +120^\circ$ or left -30° to -90° ;
increased voltage: amplitude of R or S wave in a standard lead ≥ 2 mV, S wave in lead V1 or V2 ≥ 3 mV, or R wave in lead V5 or V6 ≥ 3 mV;
abnormal Q waves ≥ 0.04 s in duration or $\geq 25\%$ of the height of the ensuing R wave or QS pattern in two or more leads;
right or left bundle branch block with QRS duration ≥ 0.12 s;
R or R' wave in lead V1 ≥ 0.5 mV in amplitude and R/S ratio ≥ 1 .

ST-segment, T-waves, and QT interval

ST-segment depression or T-wave flattening or inversion in two or more leads;
prolongation of heart rate corrected QT interval > 0.44 s in males and > 0.46 s in females.

Rhythm and conduction abnormalities

premature ventricular beats or more severe ventricular arrhythmias;
supraventricular tachycardias, atrial flutter, or atrial fibrillation;
short PR interval (< 0.12 s) with or without 'delta' wave;
sinus bradycardia with resting heart rate ≤ 40 beats/min^a;
first (PR ≥ 0.21 s^b), second or third degree atrioventricular block.

^aIncreasing less than 100 beats/min during limited exercise test.

^bNot shortening with hyperventilation or limited exercise test.

Modified from Corrado *et al.*³

ECG Criteria: *The Evolution*

Annals of Internal Medicine | ARTICLE

Cardiovascular Screening in College Athletes With and Without Electrocardiography

A Cross-sectional Study

Aaron L. Baggish, MD; Adolph M. Hutter Jr., MD; Francis Wang, MD; Kibar Yared, MD; Rory B. Weiner, MD; Eli Kupperman, BA; Michael H. Picard, MD; and Malissa J. Wood, MD

Background: Although cardiovascular screening is recommended for athletes before participating in sports, the role of 12-lead electrocardiography (ECG) remains uncertain. To date, no prospective data that compare screening with and without ECG have been available.

Objective: To compare the performance of preparticipation screening limited to medical history and physical examination with a strategy that integrates these with ECG.

Design: Cross-sectional comparison of screening strategies.

Setting: University Health Services, Harvard University, Cambridge, Massachusetts.

Participants: 510 collegiate athletes who received cardiovascular screening before athletic participation.

Measurements: Each participant had routine history and examination-limited screening and ECG. They received transthoracic echocardiography (TTE) to detect or exclude cardiac findings with relevance to sports participation. The performance of screening with history and examination only was compared with that of screening that integrated history, examination, and ECG.

Results: Cardiac abnormalities with relevance to sports participation risk were observed on TTE in 11 of 510 participants (prevalence, 2.2%). Screening with history and examination alone detected abnormalities in 5 of these 11 athletes (sensitivity, 45.5% [95% CI, 16.8% to 76.2%]; specificity, 94.4% [CI, 92.0% to 96.2%]). Electrocardiography detected 5 additional participants with cardiac abnormalities (for a total of 10 of 11 participants), thereby improving the overall sensitivity of screening to 90.9% (CI, 58.7% to 99.8%). However, including ECG reduced the specificity of screening to 82.7% (CI, 79.1% to 86.0%) and was associated with a false-positive rate of 16.9% (vs. 5.5% for screening with history and examination only).

Limitation: Definitive conclusions regarding the effect of ECG inclusion on sudden death rates cannot be made.

Conclusion: Adding ECG to medical history and physical examination improves the overall sensitivity of preparticipation cardiovascular screening in athletes. However, this strategy is associated with an increased rate of false-positive results when current ECG interpretation criteria are used.

Primary Funding Source: None.

Ann Intern Med. 2010;152:269-275. www.annals.org
For author affiliations, see end of text.

Occult cardiovascular disease is the leading cause of sudden death in young athletes (1). Consequently, all major professional medical organizations recommend preparticipation screening of athletes for underlying cardiac abnormalities (2–4). Although the mandate to screen is universal, the guidelines that delineate screening recommendations are not uniform. The American College of Cardiology and American Heart Association recommend limiting screening to a focused medical history and physical examination, whereas the European Society of Cardiology and the International Olympic Committee advocate including resting 12-lead electrocardiography (ECG). This important difference has generated considerable debate (5–7).

Outcomes from a multidecade Italian national study (8) demonstrate the positive effect of preparticipation screening and suggest an important role for ECG. Although these observational data have important limitations (9), they underscore the need for further study of proposed screening strategies (10–12). Data that define the performance of screening practices in the United States are sparse, and no studies have compared athlete screening by medical history and physical examination only with a strategy that includes ECG. For this reason, we examined the performance of preparticipation screening with history and examination only and compared it with an ECG-inclusive strategy in a large cohort of U.S. university athletes.

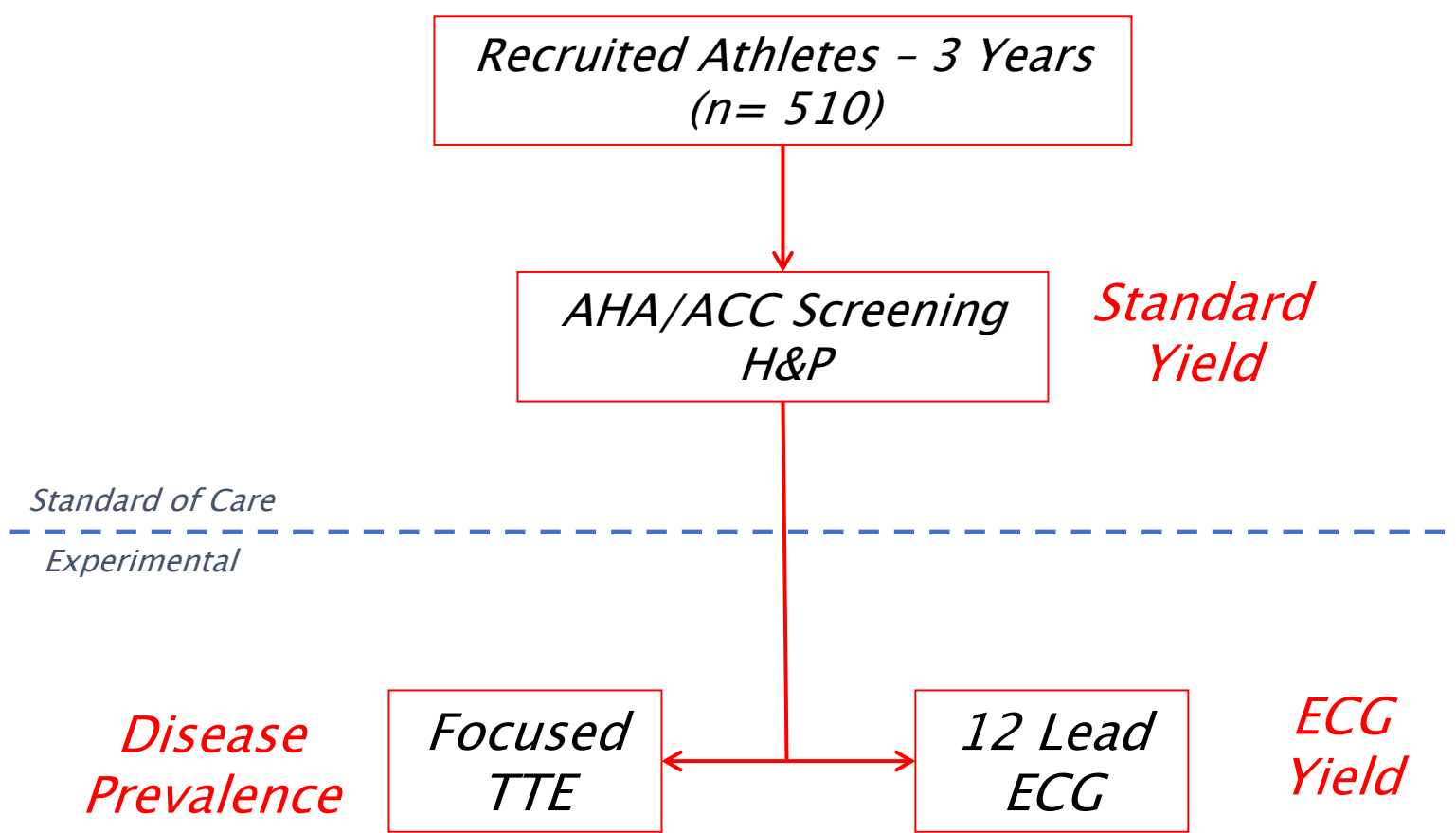
METHODS
Study Design

We conducted this study over 3 consecutive years (2006 to 2008). Athletes were eligible to participate if they were 18 years or older and were newly matriculated Har-

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Harvard Athlete Initiative (2007–2009): *Studying Screening*



ECG Criteria: *The Evolution*

Annals of Internal Medicine

ARTICLE

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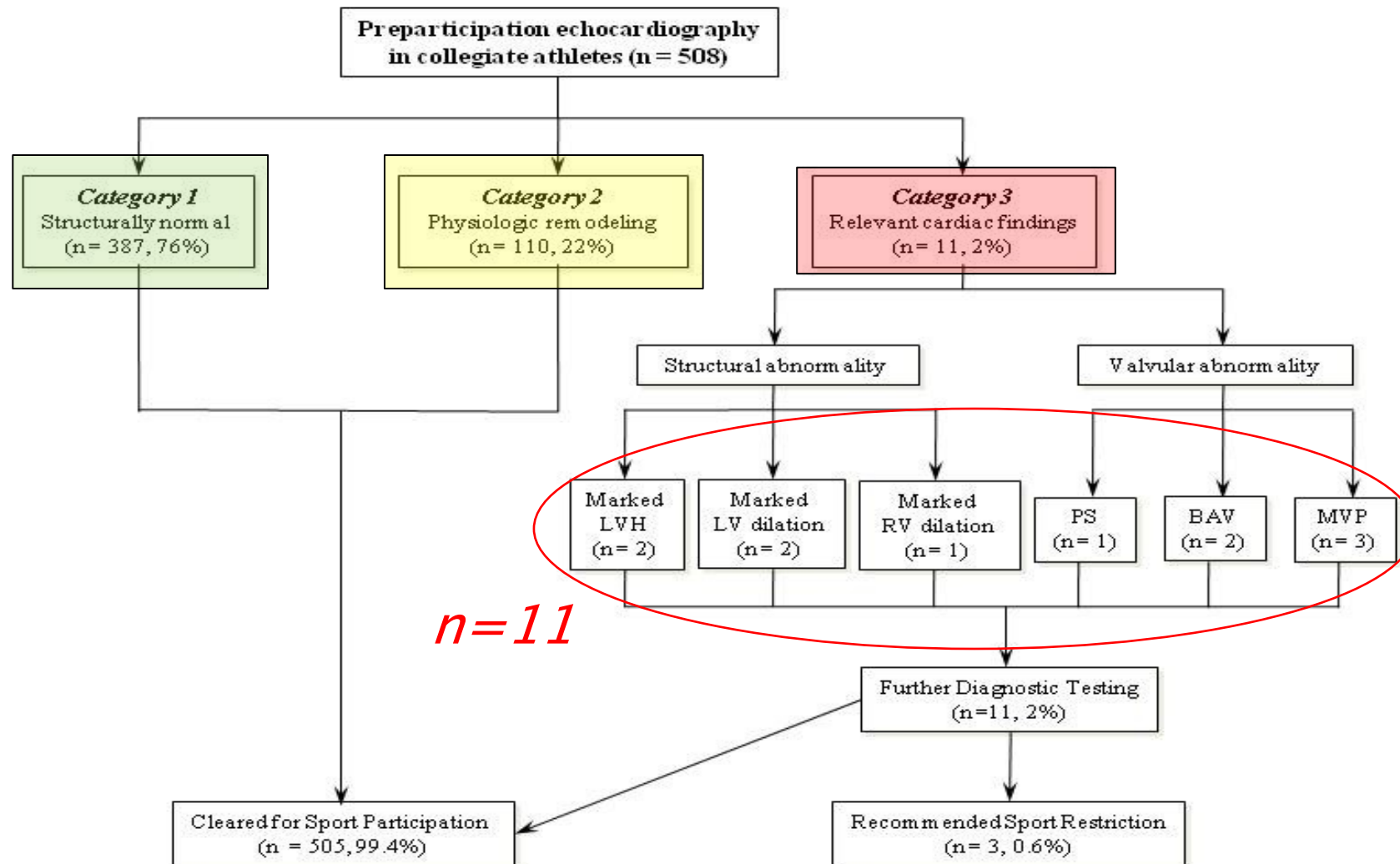
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- Appendix Tables
- Conversion of graphics into slides
- Audio summary



ECG Criteria: *The Evolution*

Annals of Internal Medicine

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Conclusion: Adding ECG to medical history and physical examination improves the overall sensitivity of preparticipation cardiovascular screening in athletes. However, this strategy is associated with an increased rate of false-positive results when current ECG interpretation criteria are used. False Positive Rate of 16.4%

Athlete	TTE Abnormality	MH/PE Finding	ECG Finding	Final Diagnosis Requiring Sport Participation Restriction
1	Bicuspid AoV			None
2	Bicuspid AoV			None
				None
				None
				None
				derate pulmonic stenosis
				None
				ertrophic cardiomyopathy
				None
				Post-viral myocarditis
11	RV dilation			None

Study Design

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Screening Strategy	
MH / PE	
MH/ PE + ECG	



European Heart Journal (2010) 31, 243–259
doi:10.1093/eurheart/ehp473

ESC REPORT

Recommendations for interpretation of 12-lead electrocardiogram in the athlete

Domenico Corrado^{1*}, Antonio Pelliccia², Hein Heidbuchel³, Sanjay Sharma⁴, Mark Link⁵, Cristina Basso⁶, Alessandro Biffi², Gianfranco Buja¹, Pietro Delise⁷, Ihor Gussac⁸, Aris Anastakis⁹, Mats Borjesson¹⁰, Hans Halvor Bjørnstad¹¹, François Carré¹², Asterios Deligiannis¹³, Dorian Dugmore¹⁴, Robert Fagard³, Jan Hoogsteen¹⁵, Klaus P. Mellwig¹⁶, Nicole Panhuyzen-Goedkoop¹⁷, Erik Solberg¹⁸, Luc Vanhees³, Jonathan Drezner¹⁹, N.A. Mark Estes, III⁵, Sabino Iliceto¹, Barry J. Maron²⁰, Roberto Peidro²¹, Peter J. Schwartz²², Ricardo Stein²³, Gaetano Thiene⁶, Paolo Zeppilli²⁴, and William J. McKenna²⁵ on behalf of the Sections of Sports Cardiology of the European Association of Cardiovascular Prevention and Rehabilitation; and the Working Group of Myocardial and Pericardial Disease of the European Society of Cardiology

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Cardiovascular remodelling in the conditioned athlete is frequently associated with physiological ECG changes. Abnormalities, however, may be detected which represent expression of an underlying heart disease that puts the athlete at risk of arrhythmic cardiac arrest during sports. It is mandatory that ECG changes resulting from intensive physical training are distinguished from abnormalities which reflect a potential cardiac pathology. The present article represents the consensus statement of an international panel of cardiologists and sports medical physicians with expertise in the fields of electrocardiography, imaging, inherited cardiovascular disease, cardiovascular pathology, and management of young competitive athletes. The document provides cardiologists and sports medical physicians with a modern approach to correct interpretation of 12-lead ECG in the athlete and emerging understanding of incomplete penetrance of inherited cardiovascular disease. When the ECG of an athlete is examined, the main objective is to distinguish between physiological patterns that should cause no alarm and those that require action and/or additional testing to exclude (or confirm) the suspicion of an underlying cardiovascular condition carrying the risk of sudden death during sports. The aim of the present position paper is to provide a framework for this distinction. For every ECG abnormality, the document focuses on the ensuing clinical work-up required for differential diagnosis and clinical assessment. When appropriate the referral options for risk stratification and cardiovascular management of the athlete are briefly addressed.

Keywords Athlete's heart • Cardiomyopathy • Electrocardiogram • Ion-channel disease • Sudden death • Ventricular fibrillation • Ventricular tachycardia

Table 1 Classification of abnormalities of the athlete's electrocardiogram

Group 1: common and training-related ECG changes

Sinus bradycardia
First-degree AV block
Incomplete RBBB
Early repolarization
Isolated QRS voltage criteria for left ventricular hypertrophy

Group 2: uncommon and training-unrelated ECG changes

T-wave inversion
ST-segment depression
Pathological Q-waves
Left atrial enlargement
Left-axis deviation/left anterior hemiblock
Right-axis deviation/left posterior hemiblock
Right ventricular hypertrophy
Ventricular pre-excitation
Complete LBBB or RBBB
Long- or short-QT interval
Brugada-like early repolarization

RBBB, right bundle branch block; LBBB, left bundle branch block.

ECG Criteria: *The Evolution*

Performance of the 2010 European Society of Cardiology criteria for ECG interpretation in the athlete

Rory B Weiner,¹ Adolph M Hutter,¹ Francis Wang,² Jonathan H Kim,¹
Malissa J Wood,¹ Thomas J Wang,¹ Michael H Picard,¹ Aaron L Baggish¹

2005 Criteria:

False Pos. Rate = 16.4%

Screening Strategy	Sensitivity	Specificity	PPV	NPV
MH / PE	45.5 (18.1,75.4)	94.4 (91.9,96.2)	15.0 (5.7,32.7)	98.7 (97.1 , 99.5)
MH/ PE + ECG	90.9 (57.1,99.5)	82.7 (79.0,85.9)	10.4 (5.4,18.7)	99.8 (98.4 , 100.0)

2010 Criteria:

False Pos. Rate = 8.6%

Screening Strategy	Sensitivity	Specificity	PPV	NPV
MH / PE	45.5 (18.1,75.4)	94.4 (91.9,96.2)	15.0 (5.7,32.7)	98.7 (97.1 , 99.5)
MH/ PE + ECG	90.9 (57.1,99.5)	91.3 (88.7,95.9)	6.5 (5.4,18.7)	100.0 (100.0 , 100.0)

Weiner et al. Heart 2010

Original Articles

Early Repolarization Pattern: Clinical Correlates and the ECG

Peter A. Noseworthy, MD; Rory Weiner, M.D.; Francis Wang, MD; Brant Berkstresser; Thomas J. Wang, MD; Michael H. Picard; Christopher Newton-Cheh, MD

Background—Inferior lead early repolarization pattern (IERP) Although IERP is common among athletes, prevalence, EC physical training remain uncertain. We sought to examine **Methods and Results**—IERP was assessed in a cross-section between ERP and cardiac structure were then examined in period of exercise training. IERP was defined as J-point elevation in inferior (II, III, aVF) or lateral territory (I, aVL, V5, V6) of athletes, including the inferior subtype in 3.8% (33% prevalence of IERP and the inferior subtype, but there was no association of IERP with left ventricular remodeling. In a multivariable model, increased QRS width (OR, 1.54; 95% CI, 1.26 to 1.87; P<0.001).

Conclusions—Nonanterior IERP, including the inferior subtype competitive athletes. The finding of increased IERP pro association between exercise and IERP. (*Circ Arrhythm Electrophysiol* 2011;5:448–455)

Key Words: exercise • electrocardiography

Since its initial description nearly 75 years ago,¹ the early repolarization pattern (ERP) has been considered a normal variant.^{2–4} However, emerging evidence from case-control^{5,6} and prospective cohort⁷ studies suggests that ERP in the inferior leads is associated with an increased risk of sudden cardiac death (SCD). The prevalence, clinical associations, and underlying mechanisms of this potentially malignant ERP subtype remains largely unstudied in young competitive athletes. Although SCD in athletes is relatively rare, it is an important clinical problem with a devastating impact on families and communities. Valuable athlete SCD registry data have shown that the majority of athlete SCD is attributable to cardiac causes but that an identifiable cardiac disorder is absent roughly one third of the time.⁸ Mechanisms and markers of electric instability in the absence of identifiable heart disease are lacking in this population.

Clinical Perspective on p 448

It is well established that ERP is more common among young athletes (prevalence estimation of 20% to 90%) than in

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From the Cardiovascular Research Center, Massachusetts General Hospital (P.A.N., C.A., A.L.B.), and Harvard University Health Services, Cambridge, MA (C.W., T.J.W., M.H.P., M.H.P., M.H.P.). Correspondence to Aaron L. Baggish, MD, Cardiovascular Performance Program, 55 Fruit St, Boston, MA 02114. E-mail: abaggish@partners.org © 2011 American Heart Association, Inc.

Circ Arrhythm Electrophysiol is available at <http://circ.ahajournals.org>.

The prevalence, distribution, and clinical outcomes of electrocardiographic repolarization patterns of African/Afro-Caribbean athletes

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Objectives Athletic training in male black athletes hypertrophic cardiomyopathy (HCM) prevalence of exercise-related sudden death

Methods and results Between 1996 and 2010, 904 BAs of African/Afro-Caribbean descent (BAs) underwent 12-lead ECGs and echocardiography. BAs were divided into three groups: normal ECGs (51%), ECGs with T-wave inversions (WAs) (19%), and ECGs with T-wave inversions in the lateral leads (LWAs) (30%).

Conclusions T-wave inversions in leads V1–V4 represent a spectrum of ECG abnormalities. In the lateral leads, they may represent a normal variant or a marker of abnormality. The prevalence of T-wave inversions in the lateral leads is related to the presence of structural and functional abnormalities of the left ventricle. The presence of T-wave inversions in the lateral leads is related to the presence of structural and functional abnormalities of the left ventricle.

Key Words: athlete's heart • Electrocardiography • Echocardiography • Left ventricle • T-wave inversion

Introduction

Participation in regular, intensive exercise is associated with normalization changes affecting the ST-segment and T-wave morphology.^{1,2} Certain electrical anomalies occasionally overlap those observed in cardiomyopathies.^{3,4} Data from Caucasian athletes [white athletes (WAs)] suggest that 3–4% of athletes exhibit T-wave inversions but their precise significance remains unclear.

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Significance of Electrocardiographic Right Bundle Branch Block in Trained Athletes

Jonathan H. Kim, MD*, Peter A. Noseworthy, MD*, Rory Weiner, MD*, Francis Wang, MD*, Malissa J. Michael, H. Picard, MD*, and Aaron L. Baggish, MD*

We sought to determine the clinical and physiological significance of right bundle branch block (CRBBB) and (IRBBB) in trained athletes. The 12-lead electrocardiogram from 510 competitive athletes were analyzed. Core gender-matched athletes with normal 12-lead electrocardiogram (ECG) dimensions, as measured by the basal RV end-diastolic diameter (RV-EDD), were compared with CRBBB (n=33, 6.5%) and IRBBB (n=27, 5.3%). CRBBB was associated with increased RV-EDD (35.2±6.1 mm vs 33.3±6.1 mm, P<0.001), increased RV-EDD, normal QRS complex 35±5 mm (CRBBB 33±5, IRBBB 27±7, and normal QRS complex 35±5 mm), normal QRS width (CRBBB 110±10 ms vs IRBBB 105±10 ms, P=0.001), and normal QRS width (CRBBB 110±10 ms vs IRBBB 105±10 ms, P=0.001). The prevalence of CRBBB and IRBBB was associated with increased RV-EDD, normal QRS complex 35±5 mm, normal QRS width (CRBBB 110±10 ms vs IRBBB 105±10 ms, P=0.001), and normal QRS width (CRBBB 110±10 ms vs IRBBB 105±10 ms, P=0.001).

At present, sparse data are available characterizing the disease prevalence, cardiac structure, and cardiac function in athletic patients with complete right bundle branch block (CRBBB) and incomplete right bundle branch block (IRBBB). We, therefore, conducted the present study with the following objectives. First, we determined the prevalence of CRBBB and IRBBB and their relations to underlying cardiac disease in a large cohort of collegiate athletes. Second, we compared the cardiac structure and function, including mechanical interventricular synchrony, among disease-free athletes with CRBBB, IRBBB, and normal 12-lead electrocardiographic QRS complex duration.

Methods

The present study population included United States university athletes previously enrolled to examine preparticipation cardiovascular disease screening.⁵ In brief, newly matriculated university athletes >18 years of age underwent a noninvestigational focused medical history and physical examination in accordance with the current American College of Cardiology/American Heart Association guidelines.² Each participant provided a designation of primary ethnicity

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ORIGINAL ARTICLE

Echocardiographic findings in 2261 peri-pubertal athletes with or without inverted T waves at electrocardiogram

Leonardo Cabó,¹ Fabio Spazzoli,^{1,2} Annamaria Elena Cavarretta,^{3,4} Federico Quaranta,^{2,1} Emerico Attilio Parisi,² Antonia Nigro,³ Antonio Spataro,⁵ and Giovanni Di Troiano^{1,2}

Objective T wave inversion (TWI) has been associated with cardiomyopathies. The hypothesis of this study was that TWI has relevant clinical significance in peri-pubertal athletes. **Methods** Consecutive male soccer players, aged 8–18 years, undergoing preparticipation screening between January 2008 and March 2009 were enrolled. Medical and family histories were collected; physical examinations, 12-lead ECGs and transthoracic echocardiogram (TTE) were performed. TWI was categorised by ECG lead (anterior (V1–V3), extended anterior (V1–V4), inferior (DI–aVF) and infero-lateral (DI–aVFA–V6/VI–aVL)) and by age. **Results** Overall, 2261 (mean age 12.4 years, 100% Caucasian) athletes were enrolled. TWI in ≥2 consecutive ECG leads was found in 136 athletes (6.0%), mostly in anterior leads (126/136, 92.6%). TWI in anterior leads was associated with TTE abnormalities in 6/126 (4.8%) athletes. TWI in extended anterior (D1–aVFA–V6/VI–aVL) and by age. **Conclusions** Overall, 2261 (mean age 12.4 years, 100% Caucasian) athletes were enrolled. TWI in ≥2 consecutive ECG leads was found in 136 athletes (6.0%), mostly in anterior leads (126/136, 92.6%). TWI in anterior leads was associated with TTE abnormalities in 6/126 (4.8%) athletes. TWI in extended anterior (D1–aVFA–V6/VI–aVL) and by age.

Conclusions Overall, 2261 (mean age 12.4 years, 100% Caucasian) athletes were enrolled. TWI in ≥2 consecutive ECG leads was found in 136 athletes (6.0%), mostly in anterior leads (126/136, 92.6%). TWI in anterior leads was associated with TTE abnormalities in 6/126 (4.8%) athletes. TWI in extended anterior (D1–aVFA–V6/VI–aVL) and by age.

INTRODUCTION

The prevalence and clinical significance of T wave inversion (TWI) at ECG in young athletes has been a subject of investigation.^{1–5} Previous studies have shown that TWI in leads V1–V2 are relatively rare among athletes, with a prevalence ranging from 2.5%, to 4.7%,⁶ and 0.8% when they extend to V3.⁷ TWI in infero-lateral has been described in 1.5%–1.8% of postpubertal Caucasian athletes,^{6,8} and inverted T waves confined to lateral leads were observed in 0.1%–0.3% of young athletes.^{4, 9} Although independent from training-related physiological cardiac remodeling,¹⁰ in the absence of

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ECG findings in competitive rowers: normative data and the prevalence of abnormalities using contemporary screening recommendations

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Background/Aim The International governing body for competitive rowing recently mandated the inclusion of 12-lead ECG during preparticipation screening. We therefore sought to describe normative ECG characteristics and to examine the prevalence of abnormal ECG findings as defined by contemporary athlete ECG interpretation criteria among competitive rowers. **Methods** Competitive rowers (n=330, 56% male) underwent standard 12-lead ECG at the time of collegiate preparticipation screening. ECGs were analysed quantitatively to develop a sport-specific normative database and then for the presence of abnormalities in accordance with the 2010 European Society of Cardiology (ESC) recommendations and 2013 Seattle Criteria.⁵ **Results** 94% of rowers had one or more training-related ECG patterns including sinus bradycardia (51%), sinus arrhythmia (55%), and incomplete right bundle branch block (42%). Males were more likely than females to have isolated voltage criteria for left ventricular hypertrophy (LVH) (51% vs 8%, p<0.001) and early repolarisation pattern (76% vs 23%, p<0.001). Application of the 2010 ESC criteria, compared to the Seattle criteria, resulted in the diagnosis of a significantly greater number of abnormal ECGs (47% vs 4%, p<0.001). The detection of true pathology, accomplished by both interpretation criteria, was confined to a single case of ventricular pre-excitation.

Conclusions Training-related ECG patterns with several gender-based differences are common among competitive rowers. The diagnostic accuracy and downstream clinical implications of ECG-inaccuracy preparticipation screening among rowers will be dictated by the choice and future refinement of ECG interpretation criteria.

INTRODUCTION

Occult cardiovascular disease is the leading cause of sudden death among competitive athletes.^{1,2} The majority of cardiovascular disorders responsible for sudden death during sport may be identified by abnormal findings on the 12-lead ECG.^{3–5} ECG is therefore commonly employed during the diagnostic evaluation of symptomatic athletes and is increasingly used during preparticipation screening. Fédération Internationale des Sociétés d'Aviron

(FISA), the international governing body for competitive rowing, recently mandated ECG-inaccuracy preparticipation screening prior to international regatta.⁶ The heart adapts to repeated bouts of intense exercise. Exercise-induced cardiac remodelling including changes in chamber size,⁷ wall thickness⁷ and function^{8,9} have been documented in competitive rowers. Several large cross-sectional studies have described coronary artery findings in trained athletes,^{10–13} and have led to the concept of “training-related ECG patterns.” However, rowers constitute a minority of the athletes represented in these studies and have only been specifically examined in small cohorts.^{14–16} As such, there are relatively limited data defining the sport-specific spectrum of ECG findings among competitive rowers. We therefore performed a comprehensive analysis of ECG findings in a sizable cohort of competitive rowers with two distinct yet complementary goals. First, we sought to develop a normative database of ECG patterns in this population. Second, we aimed to examine the prevalence of abnormal ECG findings as defined by contemporary criteria that have been developed for ECG interpretation in athletes.^{17,18}

METHODS

Study design We utilised a cross-sectional and longitudinal study design to examine the ECG characteristics and clinical follow-up of collegiate rowers at Harvard University. The Harvard University crew is a competitive programme that routinely attracts international calibre men and women rowers from across the world. Participants were enrolled over consecutive years (2006–2013) during preparticipation screening sessions conducted within the Harvard Athletic Initiative (HAI). The HAI is a research collaboration designed to facilitate the study of cardiovascular health and physiology in student athletes. Participants consisted of newly matriculated male and female rowers ≥18 years of age. Demographic information including age, self-reported ethnicity, country of origin, preseason training volume, height and body mass were obtained for each participant. Next, each rower underwent standardised, non-investigational screening medical history and physical examination based on current American College of Cardiology and American Heart Association recommendations.¹⁹

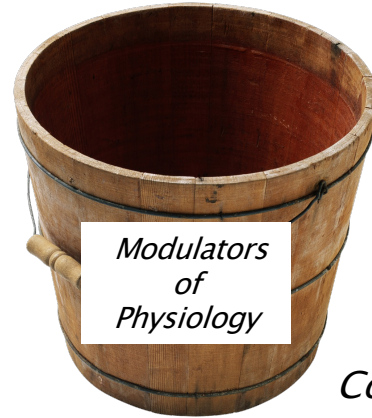
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ECG Criteria: *The Evolution*

February 2012

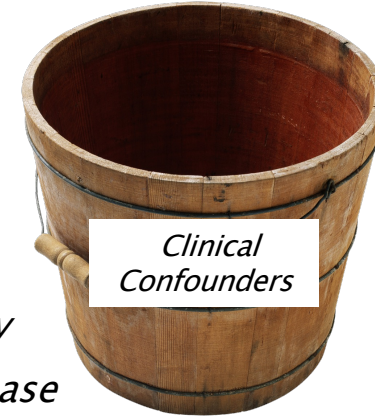


Identify Key Sources of ECG Variability



Modulators
of
Physiology

Age
Gender
Ethnicity
Sport-type
Med / PEDs
Duration of play
Concomitant disease



Clinical
Confounders

Hyperopia (Farsighted)



Population Focus
Maximal Sensitivity at the Expense of Outliers
Conservative & Safe
High False + Testing Rates

Vs.

Myopia (Nearsighted)



Patient Focus
Maximal Specificity at the Risk of Under diagnosis
? Cavalier
High False - Testing

International Recommendations for Electrocardiographic Interpretation in Athletes

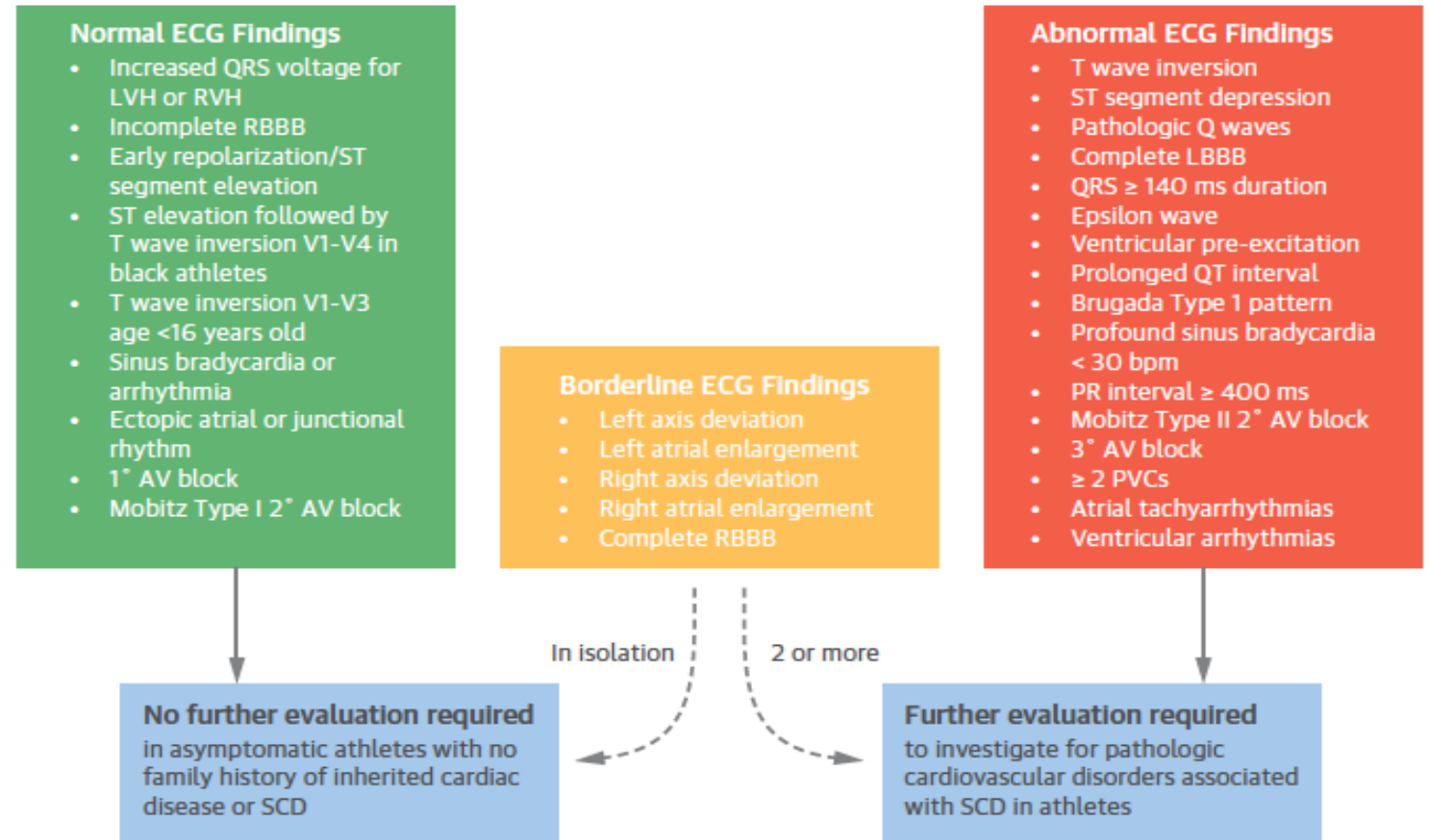
Sanjay Sharma, MD,^{1,2,3,4} Jonathan A. Drezner, MD,^{2,3,4} Aaron Baggish, MD,⁵ Michael Papadakis, MD,⁶ Matthew G. Wilson, PhD,⁷ Jordan M. Prutkin, MD, MHS,⁸ Andre La Gerche, MD, PhD,⁹ Michael J. Ackerman, MD, PhD,¹⁰ Mats Björjeson, MD, PhD,¹¹ Jack C. Salerno, MD,¹² Ifan M. Asif, MD,¹³ David S. Owens, MD, MS,¹⁴ Eugene H. Chung, MD, MS,¹⁵ Michael S. Emery, MD,¹⁶ Victor F. Froelicher, MD,¹⁷ Hein Heidbuchel, MD, PhD,^{18,19} Carmen Adamuz, MD, PhD,²⁰ Chad A. Asplund, MD,²¹ Gordon Cohen, MD,²² Kimberly G. Harmon, MD,²³ Joseph C. Marek, MD,²⁴ Silvana Molossi, MD,²⁵ Josef Niebauer, MD, PhD,²⁶ Hank F. Peito, MD,²⁷ Marco V. Perez, MD,²⁸ Nathan R. Riding, PhD,²⁹ Tess Saarel, MD,³⁰ Christian M. Schmied, MD,³¹ David M. Shipon, MD,³² Ricardo Stein, MD, ScD,³³ Victoria L. Vetter, MD, MPH,³⁴ Antonio Pelliccia, MD,³⁵ Domenico Corrado, MD, PhD³⁶

ABSTRACT

Sudden cardiac death (SCD) is the leading cause of mortality in athletes during sport. A variety of mostly hereditary, structural, or electrical cardiac disorders are associated with SCD in young athletes, the majority of which can be identified or suggested by abnormalities on a resting 12-lead electrocardiogram (ECG). Whether used for diagnostic or screening purposes, physicians responsible for the cardiovascular care of athletes should be knowledgeable and competent in ECG interpretation in athletes. However, in most countries a shortage of physician expertise limits wider application of the ECG in the care of the athlete. A critical need exists for physician education in modern ECG interpretation that distinguishes normal physiological adaptations in athletes from distinctly abnormal findings suggestive of underlying pathology. Since the original 2010 European Society of Cardiology recommendations for ECG interpretation in athletes, ECG standards have evolved quickly over the last decade, pushed by a growing body of scientific data that both tests proposed criteria sets and establishes new evidence to guide refinements. On February 26-27, 2015, an international group of experts in sports cardiology, inherited cardiac disease, and sports medicine convened in Seattle, Washington, to update contemporary standards for ECG interpretation in athletes. The objective of the meeting was to define and revise ECG interpretation standards based on new and emerging research and to develop a clear guide to the proper evaluation of ECG abnormalities in athletes. This statement represents an international consensus for ECG interpretation in athletes and provides expert opinion-based recommendations linking specific ECG abnormalities and the secondary evaluation for conditions associated with SCD. (J Am Coll Cardiol 2017;69:1057-75) © 2017 The Authors. Published by Elsevier Inc. on behalf of American College of Cardiology Foundation. All rights reserved.

This article has been co-published in the *European Heart Journal* and the *Journal of the American College of Cardiology*. An extended version of this article has also been jointly published in the *British Journal of Sports Medicine*. From the ¹Cardiology Clinical and Academic Group, St George's University of London, United Kingdom; ²Department of Family Medicine, University of Washington, Seattle, Washington; ³Division of Cardiology, Massachusetts General Hospital, Boston, Massachusetts; ⁴Department of Sports Medicine, ASSETAR, Qatar Orthopaedic and Sports Medicine Hospital, Qatar; ⁵Division of Cardiology, University of Washington, Seattle, Washington; ⁶Department of Cardiology, Baker IDI Heart and Diabetes Institute, Melbourne, Australia; ⁷Department of Cardiovascular Diseases, Pediatric and Adolescent Medicine, and Molecular Pharmacology and Experimental Therapeutics, Mayo Clinic, Rochester, Minnesota; ⁸Department of Neuroscience and Physiology, Sahlgrenska University Hospital Östra Sahlgrenska Academy, Gothenburg, Sweden; ⁹Department of Pediatrics, University of Washington, Seattle, Washington; ¹⁰Department of Family Medicine, University of South Carolina, Greenville, South Carolina; ¹¹Division of Cardiology, University of North Carolina School of Medicine, Chapel Hill, North Carolina; ¹²Center of Cardiovascular Care in Athletics, Indiana University School of Medicine, Indianapolis, Indiana; ¹³Department of Medicine, Stanford University, Stanford, California; ¹⁴Department of Cardiology, Arsythology Hasselt University, Belgium; ¹⁵Department of Cardiology, Antwerp, Belgium; ¹⁶Georgia

FIGURE 1 International Consensus Standards for Electrocardiographic Interpretation in Athletes

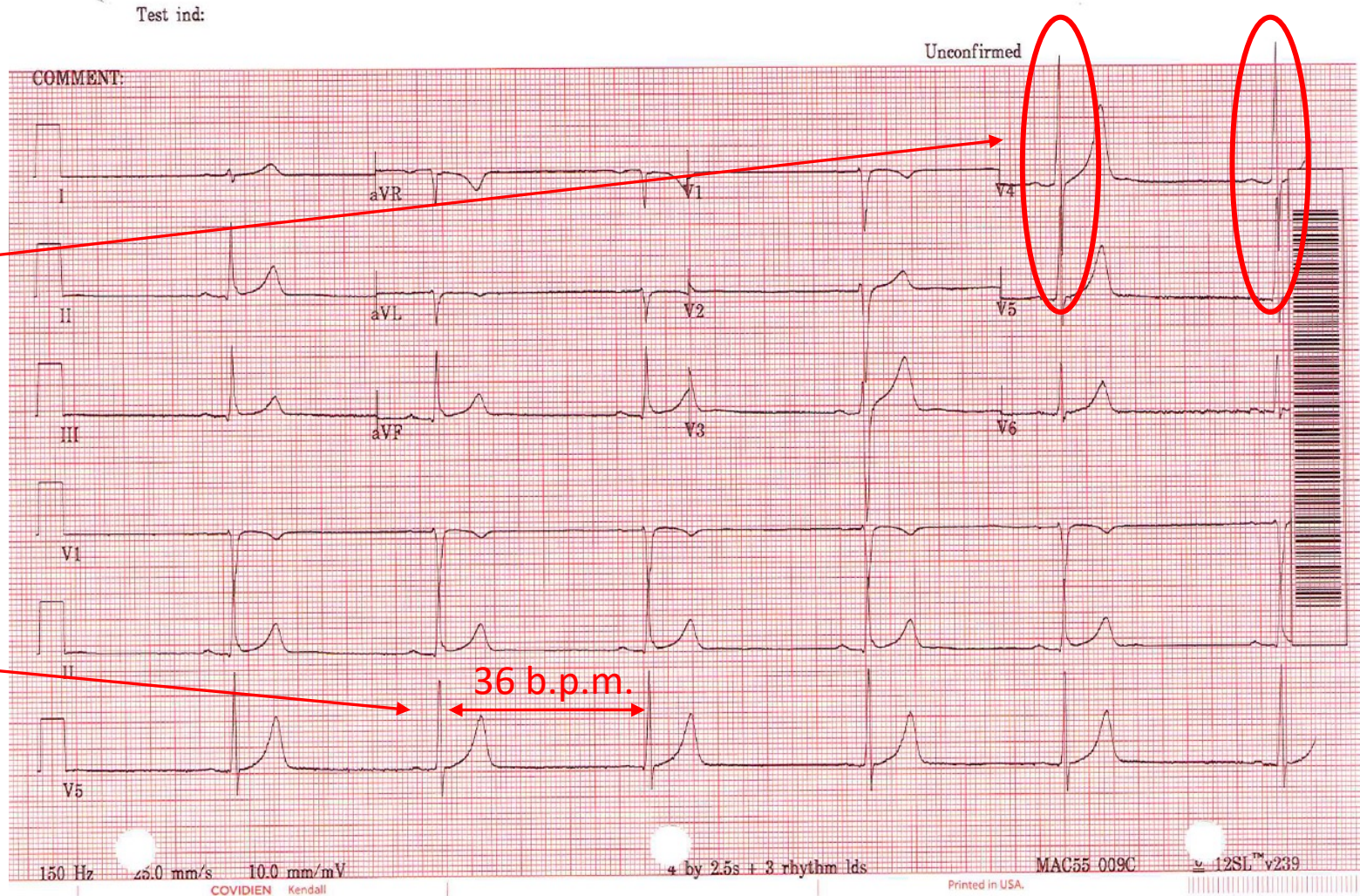


AV = atrioventricular block; LBBB = left bundle branch block; LVH = left ventricular hypertrophy; RBBB = right bundle branch block; RVH = right ventricular hypertrophy; PVC = premature ventricular contraction; SCD = sudden cardiac death.

22 y.o. White Male Long Distance Runner

Normal ECG Findings

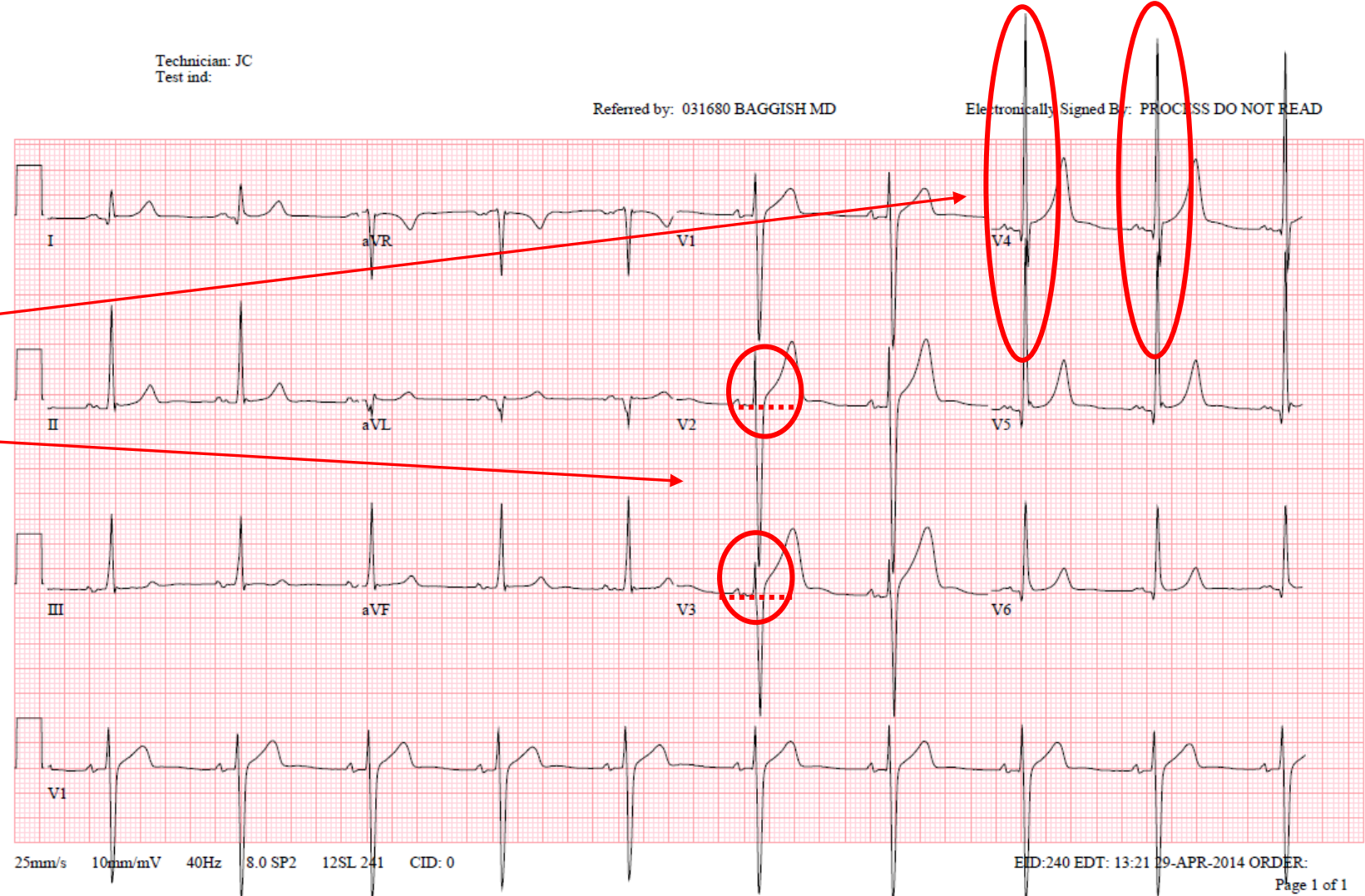
- Increased QRS voltage for LVH or RVH
- Incomplete RBBB
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion V1-V4 in black athletes
- T wave inversion V1-V3 age <16 years old
- Sinus bradycardia or arrhythmia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block



23 y.o. Black Female Sprinter / Hurdler

Normal ECG Findings

- Increased QRS voltage for LVH or RVH
- Incomplete RBBB
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion V1-V4 in black athletes
- T wave inversion V1-V3 age <16 years old
- Sinus bradycardia or arrhythmia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block



Pre-participation Screening

26 y.o. White Female
Long Distance Runner

25-SEP-1976 (38 yr)
Male Caucasian
72in 190lb
Room:
Loc:46

Vent. rate 40 BPM
PR interval 170 ms
QRS duration 114 ms
QT/QTc 486/396 ms
P-R-T axes 26 52 47

SINUS BRADYCARDIA
INTRAVENTRICULAR CONDUCTION DEFECT
OTHERWISE TRACING IS WITHIN NORMAL LIMITS

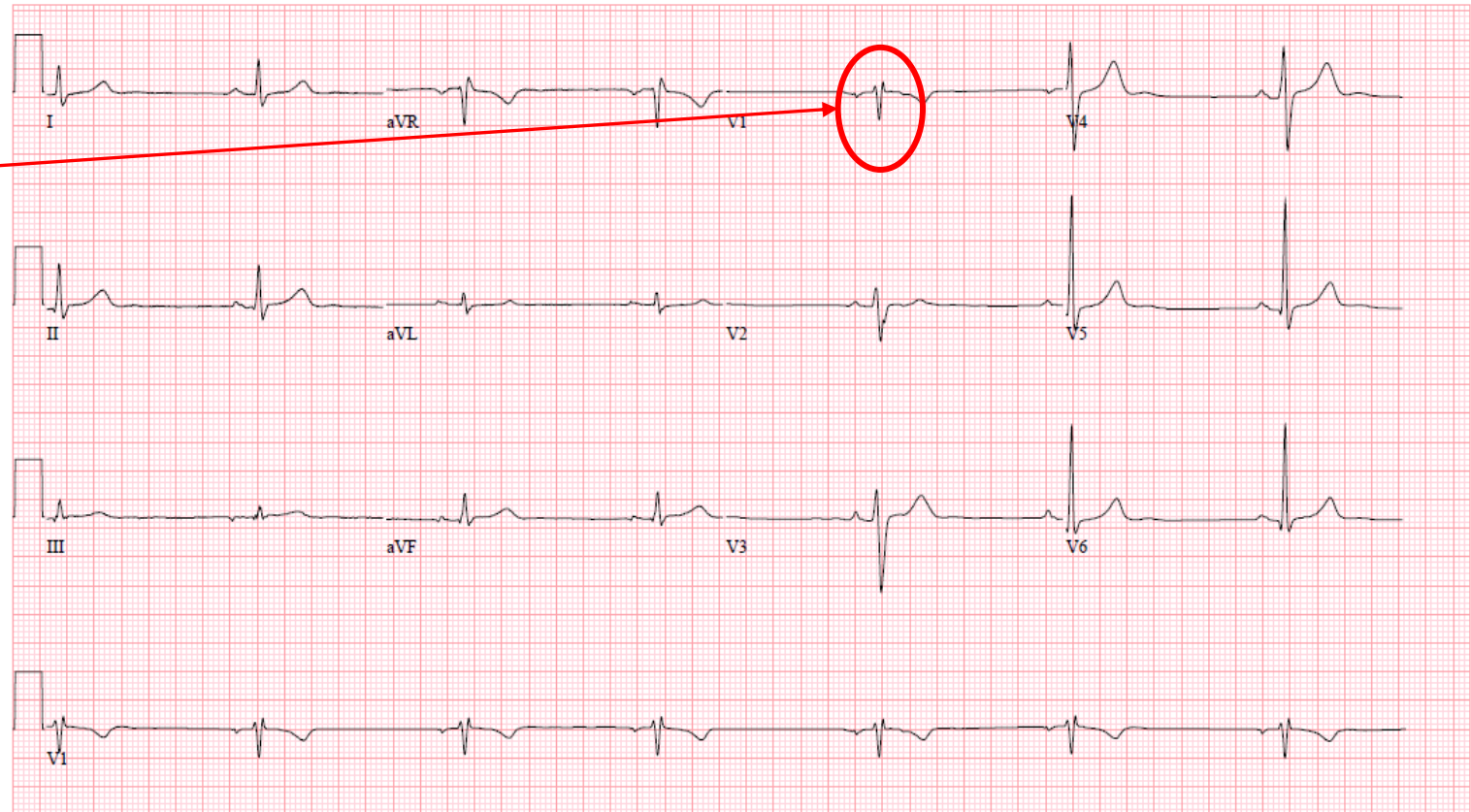
Technician: ED
Test ind: V71.7

Referred by: 031680

Electronically Signed By: AARON L. BAGGISH, M.D.

Normal ECG Findings

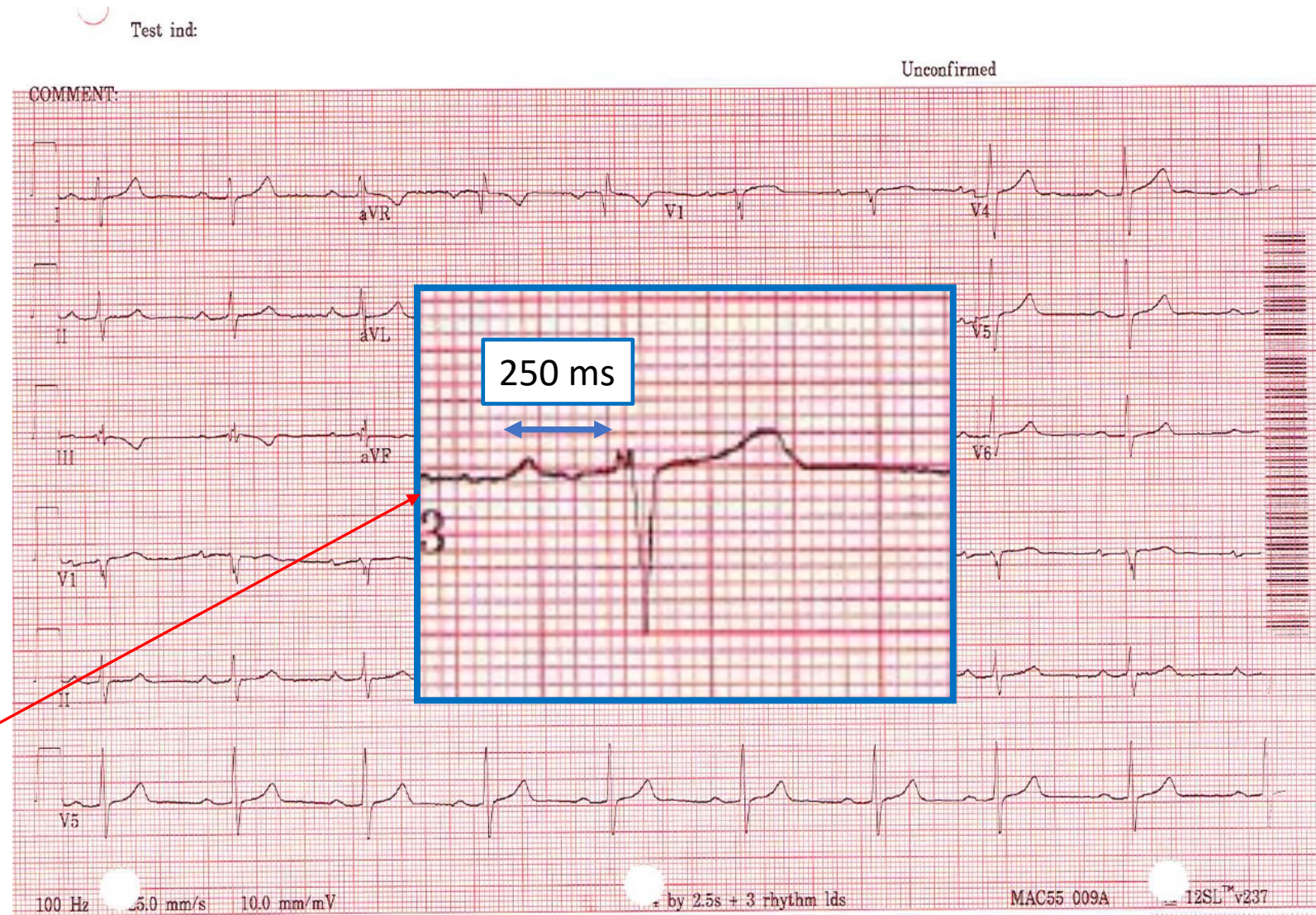
- Increased QRS voltage for LVH or RVH
- **Incomplete RBBB**
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion V1-V4 in black athletes
- T wave inversion V1-V3 age <16 years old
- Sinus bradycardia or arrhythmia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block



31 y.o. Black Male Marathoner

Normal ECG Findings

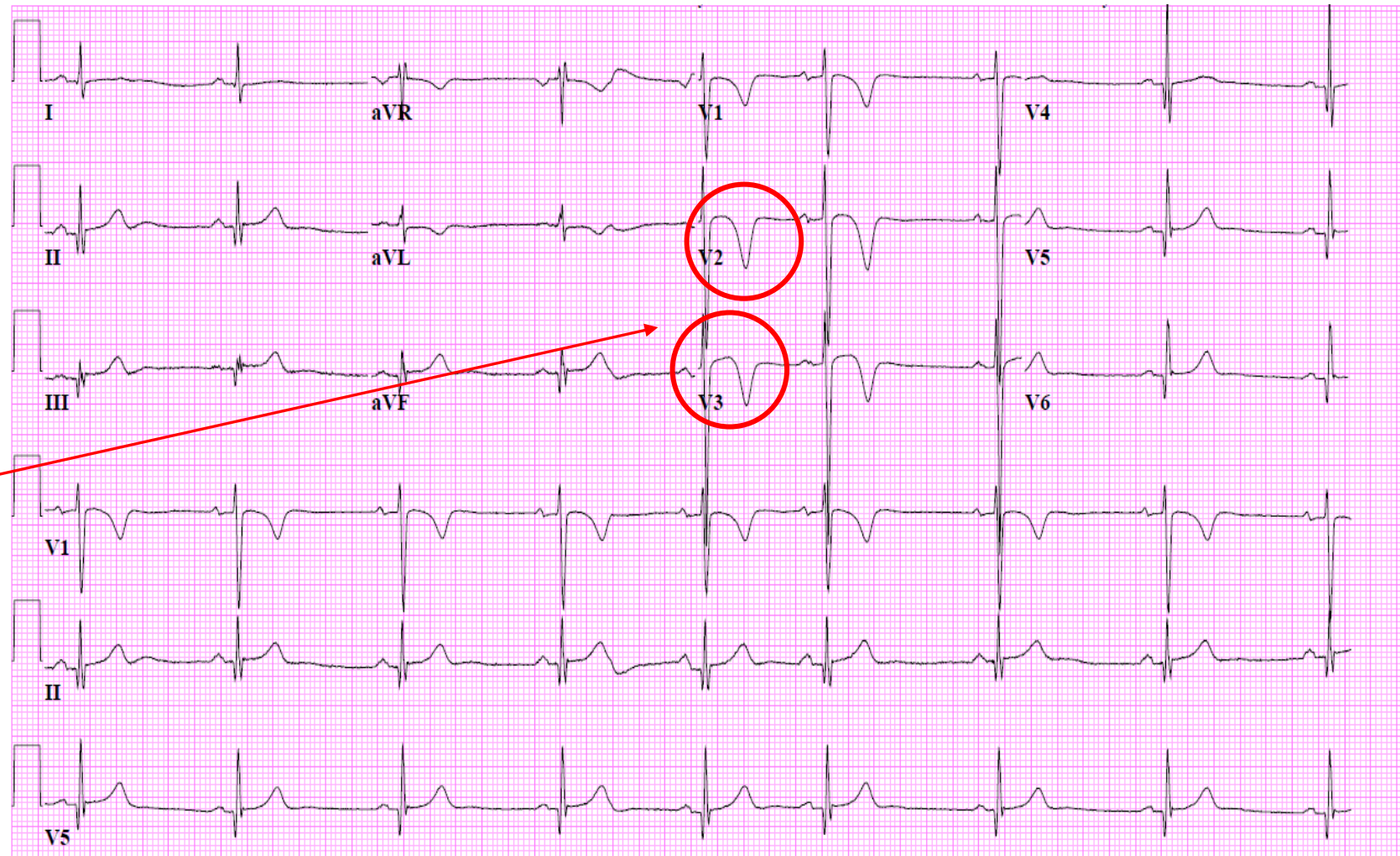
- Increased QRS voltage for LVH or RVH
- Incomplete RBBB
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion V1-V4 in black athletes
- T wave inversion V1-V3 age <16 years old
- Sinus bradycardia or arrhythmia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block



27 y.o. Black Male Sprinter

Normal ECG Findings

- Increased QRS voltage for LVH or RVH
- Incomplete RBBB
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion V1-V4 in black athletes
- T wave inversion V1-V3 age <16 years old
- Sinus bradycardia or arrhythmia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block



22 y.o. White Male Discus Thrower

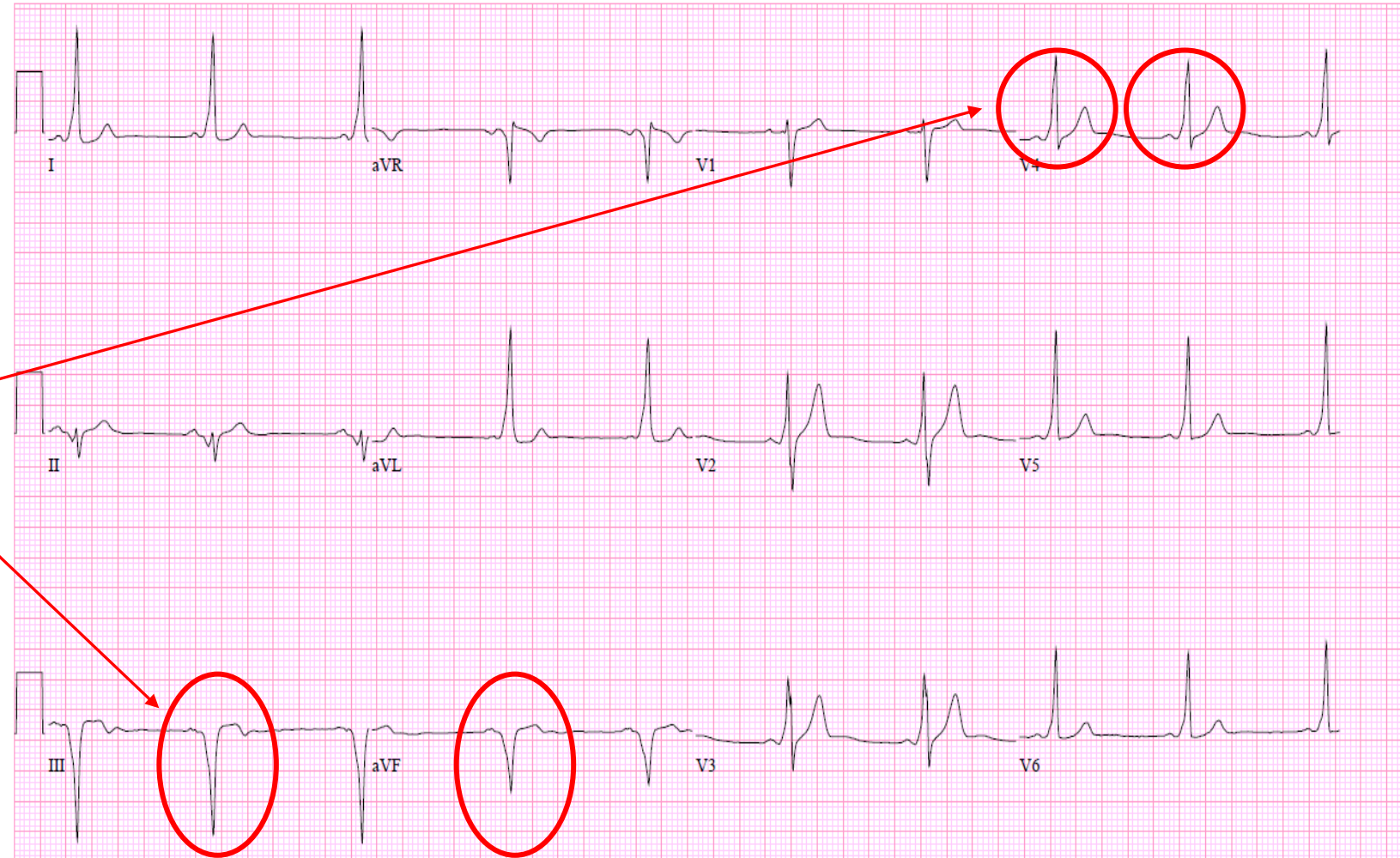
Med: None

Referred by: TREADWAY IMA

Confirmed By: DR. TREADWAY, IMA 4

Abnormal ECG Findings

- T wave inversion
- ST segment depression
- Pathologic Q waves
- Complete LBBB
- QRS ≥ 140 ms duration
- Epsilon wave
- **Ventricular pre-excitation**
- Prolonged QT interval
- Brugada Type 1 pattern
- Profound sinus bradycardia < 30 bpm
- PR interval ≥ 400 ms
- Mobitz Type II 2° AV block
- 3° AV block
- ≥ 2 PVCs
- Atrial tachyarrhythmias
- Ventricular arrhythmias



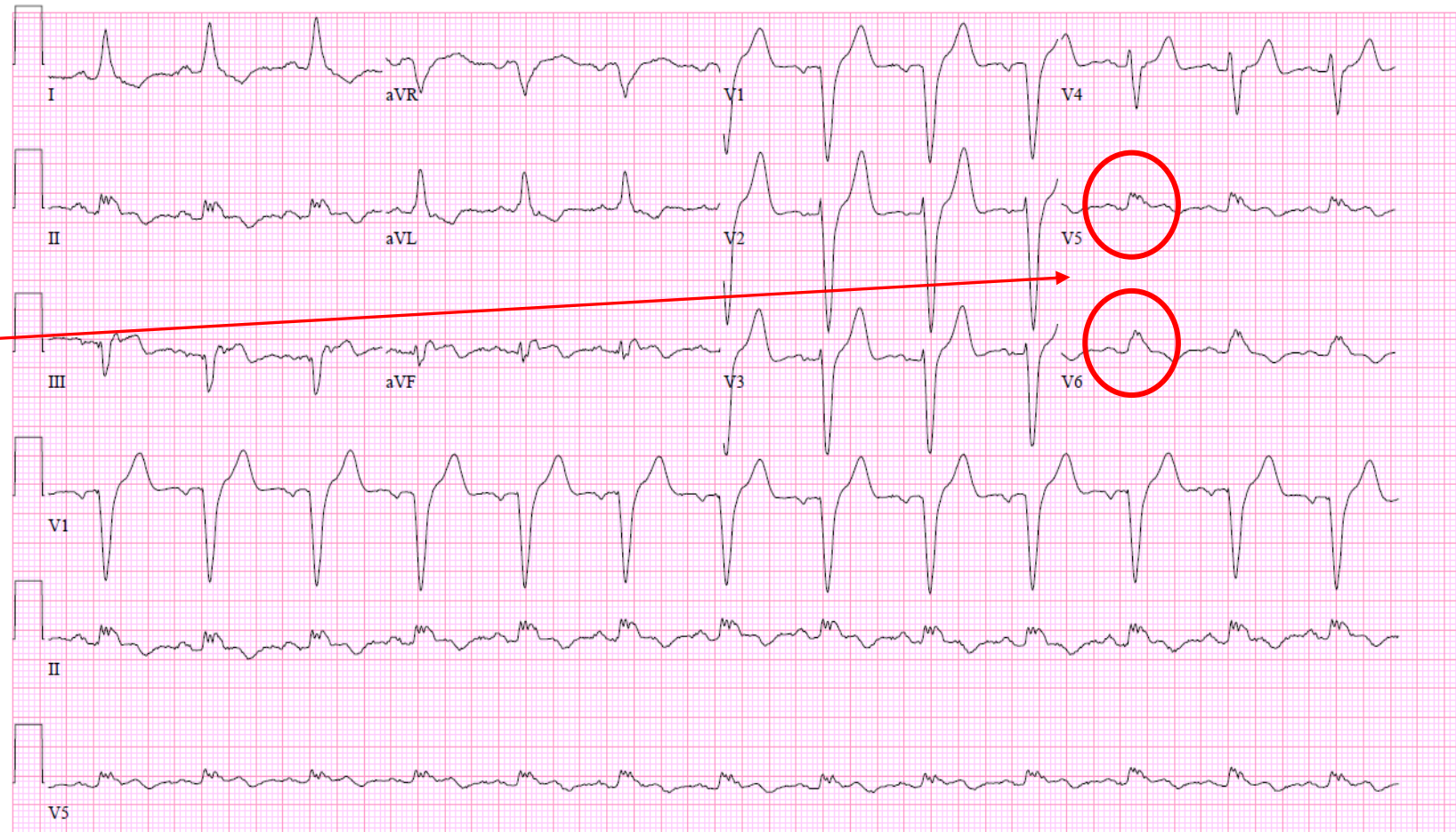
21 y.o. White Male
XC Runner

Abnormal ECG Findings

- T wave inversion
- ST segment depression
- Pathologic Q waves
- Complete LBBB
- QRS ≥ 140 ms duration
- Epsilon wave
- Ventricular pre-excitation
- Prolonged QT interval
- Brugada Type 1 pattern
- Profound sinus bradycardia < 30 bpm
- PR interval ≥ 400 ms
- Mobitz Type II 2° AV block
- 3° AV block
- ≥ 2 PVCs
- Atrial tachyarrhythmias
- Ventricular arrhythmias

Referred by:

Confirmed By: K. BLOCH, M.D.



25mm/s 10mm/mV 40Hz 005C 12SL 233 CID: 1

EID:202 EDT: 10:45 11-JUN-2004 ORDER:

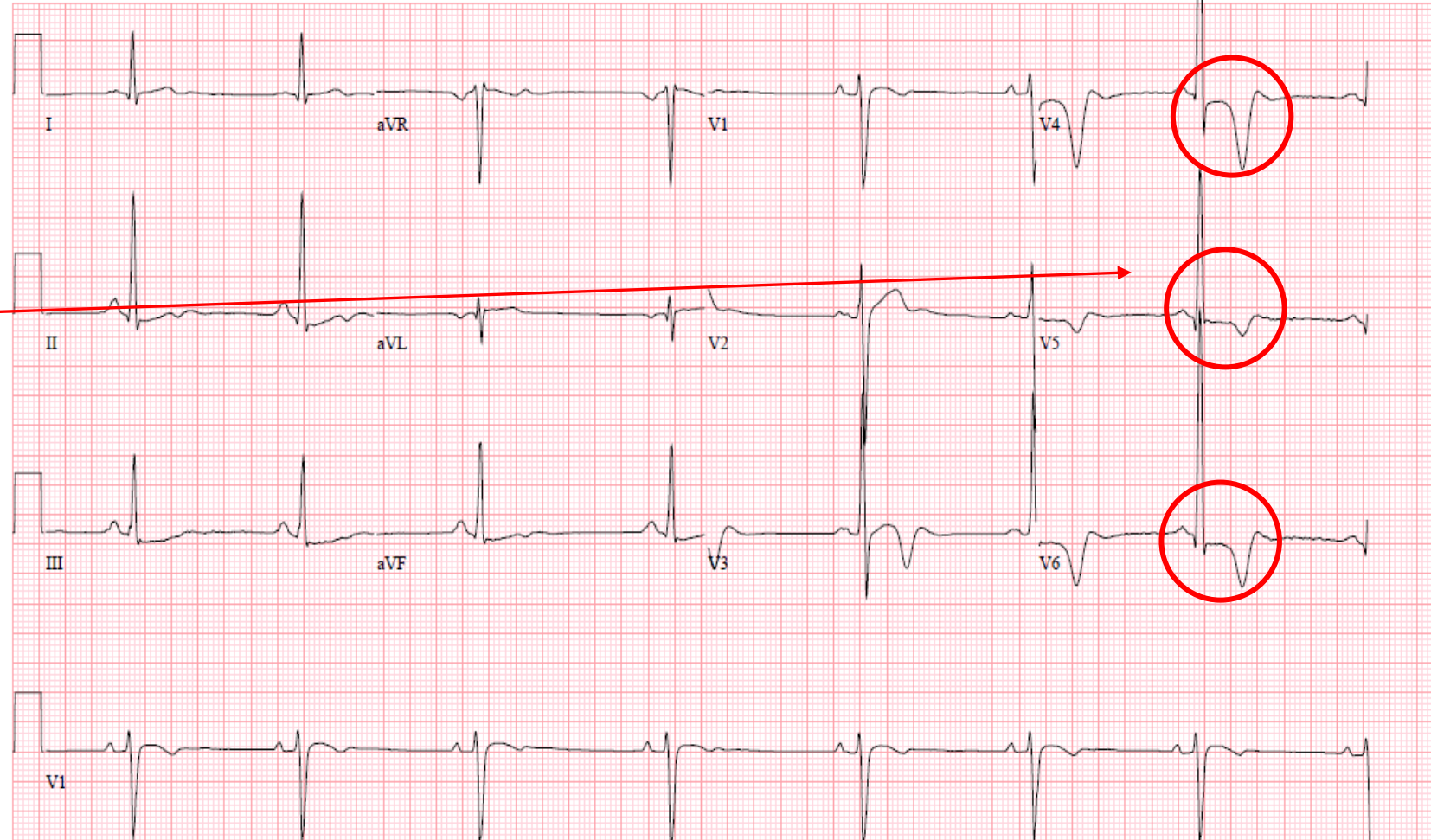
Referred by: 031680 BAGGISH

Electronically Signed By: PROCESS DO NOT READ

29 y.o. Black Male Shotput Thrower

Abnormal ECG Findings

- T wave inversion
- ST segment depression
- Pathologic Q waves
- Complete LBBB
- QRS ≥ 140 ms duration
- Epsilon wave
- Ventricular pre-excitation
- Prolonged QT interval
- Brugada Type 1 pattern
- Profound sinus bradycardia < 30 bpm
- PR interval ≥ 400 ms
- Mobitz Type II 2° AV block
- 3° AV block
- ≥ 2 PVCs
- Atrial tachyarrhythmias
- Ventricular arrhythmias



25mm/s 10mm/mV 40Hz 8.0 SP2 12SL 241 HD CID: 0

EID:239 EDT: 08:24 14-APR-2015 ORDER:

Indeed, the “Athlete’s ECG” can be dramatic.....

Practical Considerations about the 12-lead ECG

- ✓ **Technique** matters, first thing to consider is whether finding is a technical issue
 - ✓ **Pre-test probability** defines response to findings
 - ✓ **ECG’s in isolation** are of limited value ≠ CLEARANCE
- ✓ **Diagnostic Criteria** have been developed to help with this process
- ✓ **Consistency** is key and requires repetition and systematic approach

SCD Prevention in Athletes

Practice
Discuss
Work with Experts

PRACTICE
Makes **PERFECT**
★ Makes **PROGRESS**
★ Brings understanding of what **WORKS** and what doesn't work.
★ **UP** your **SKILL** level.
★ Checks **new HABITS**.
★ Builds **CONFIDENCE**

We will never be perfect, so let's be ready!

CPR/AED Training for All Athletes and Stakeholders



+

Rehearsed Emergency Action Plan for Cardiac Arrest



+

Regional Referral Centers and Uploaded Cardiac Information



Physician Leaders in the Community Have a Responsibility and an Opportunity

Thank You

