The International Criteria for ECG Interpretation in Athletes

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Disclosures

• No relevant financial relationships
Why ECG?

| Diagnostic                     | Screening                      |
|================================|--------------------------------|
| Symptoms                       | Cardiomyopathy                 |
| Abnormal physical exam         | Ion channel disorders          |
| Family history                 | Pre-excitation                 |

- Accurate ECG interpretation requires:
  1. Knowledge of the physiological adaptations in athlete’s heart
  2. Understanding of ECG abnormalities suggestive of a pathological disorder
  3. Proper secondary investigation of an abnormal ECG
  4. Training and experience
  5. Cardiology resources
Outline

- Evolution of ECG interpretation standards
- **International Criteria**
- 6-steps to ECG interpretation in athletes
- Examples!
- Getting started
- Resources
Evolution of ECG Interpretation in Athletes

Refined Criteria Training Related Normal Variants
Not Warranting Further Investigation*

- Sinus bradycardia
- First-degree AV block
- Incomplete RBBB
- Early repolarisation
- Isolated QRS voltage criteria for LVH

Refined Criteria Borderline Variants
Potentially Warranting Further Investigation

- Left atrial enlargement
- Right atrial enlargement
- Left axis deviation
- Right axis deviation
- Right ventricular hypertrophy
- TWI up to V4 in BAs†

Refined Criteria Training Unrelated Changes
Warranting Further Investigation

- ST-segment depression
- Pathological Q-waves
- Ventricular pre-excitation
- TWI beyond V1 in WAs beyond V4 in BAs
- Complete LBBB or RBBB
- QTc ≥470 ms in males
  ≥480 ms in females
- Brugada-like ER
- Atrial or vent. arrhythmias
- ≥2 PVCs per 10 sec tracing

If present in ISOLATION*

If TWO OR MORE present

Epidemiology and Prevention

Comparison of Electrocardiographic Criteria for the Detection of Cardiac Abnormalities in Elite Black and White Athletes

Nabeel Sheikh, MRCP; Michael Papadakis, MRCP; Saqib Ghani, MRCP; Abbas Zaïdi, MRCP; Sabiha Gati, MRCP; Paolo Emilio Adamo, MD; François Carré, PhD; Frédéric Schnell, PhD; Mathew Wilson, PhD; Paloma Avila, MD; William McKenna, MD, DSc, FESC; Sanjay Sharma, MD, FRCP, FESC (UK)
International recommendations for electrocardiographic interpretation in athletes


International Recommendations for Electrocardiographic Interpretation in Athletes

Sanjay Sharma, MD, Jonathan A. Drezner, MD, Aaron Baggish, MD, Michael Papadakis, MD, Mathew G. Wilson, PhD, Jordan M. Prutkin, MD, MHS, André La Gerche, MD, PhD, Michael J. Ackerman, MD, PhD, Irfan M. Asif, MD, David S. Owens, MD, PhD, F. Froelicher, MD, Hein Heldhaber, MD, PhD, D. Cohen, MD, Kimberly G. Harmon, MD, J. Cohen, PhD, Hank F. Pelto, MD, Marco V. Perez, MD, Antonio Pelliccia, MD, and Domenico Corrado, MD

International criteria for electrocardiographic interpretation in athletes

Jonathan A Drezner,1 Sanjay Sharma,2 Aaron Baggish,3 Michael Papadakis,2 Mathew G Wilson,4 Jordan M Prutkin,5 André La Gerche,6 Michael J Ackerman,7,8,9,10,11 Mats Borjesson,12,13 Jack C Salerno,14 Irfan M Asif,15 David S Owens,16 Eugene H Chung,17 Michael S Emery,18 Victor F Froelicher,19 Hein Heldhaber,20 Gordon Cohen,21,22 Kimberly G Harmon,1 Joseph C Marek,23 Silvana Molossi,24,25 Josef Niebauer,26 Hank F Pelto,27 Marco V Perez,21 Nathan R Riding,4 Tess Saarel,18,28,29 Christian M Schmied,30 David M Shipon,31 Ricardo Stein,25 Victoria L Vetter,33 Antonio Pelliccia,34 and Domenico Corrado36,39,40

This statement has been endorsed by the following societies: American Medical Society for Sports Medicine (AMSSM), Austrian Society of Sports Medicine and Prevention, Brazilian Society of Cardiology – Department of Exercise and Rehabilitation (SBCT – DER), British Association for Sports and Exercise Medicine (BASEM), Canadian Academy of Sport and Exercise Medicine (CASEM), European College of Sports and Exercise Physicians (ECOSEP), European Society of Cardiology (ESC) Section of Sports Cardiology, Fédération Internationale de Football Association (FIFA), German Society of Sports Medicine and Prevention, International Olympic Committee (IOC), Norwegian Association of Sports Medicine and Physical Activity (NIMP), South African Sports Medicine Association (SASMA), Spanish Society of Cardiology (SEC) Sports Cardiology Group, Sports Doctors Australia, and the Swedish Society of Exercise and Sports Medicine (SFAM). The American College of Cardiology (ACC) affirms the value of this document. ACC supports the general principles in the document and believes it is of general benefit to its membership.

Freely available at: http://bjsm.bmj.com/content/early/2017/03/03/bjsports-2016-097331
1. Update ECG interpretation standards based on new and emerging research

2. Develop clear guide to the appropriate evaluation of ECG abnormalities for conditions associated with SCD in athletes
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

Borderline ECG Findings
- Left axis deviation
- Left atrial enlargement
- Right axis deviation
- Right atrial enlargement
- Complete RBBB

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

No further evaluation required in asymptomatic athletes with no family history of inherited cardiac disease or SCD

Further evaluation required to investigate for pathologic cardiovascular disorders associated with SCD in athletes
Key Changes: Seattle Criteria to the International Criteria

1. ECG guidelines for athletes age 12-16 years and recognition of juvenile T wave inversion as normal
2. Introduction of a “yellow” list or borderline findings (RBBB, axis deviation, atrial enlargement) in which ≥2 require more evaluation
3. New definition for pathologic Q waves
4. TWI ≥1 mm in V5 or V6 alone warrants more investigation
5. Epsilon wave added to “red” list
6. Findings that warrant evaluation for coronary artery disease in athletes ≥30 years
7. Recommendations for secondary testing
Does modifying the criteria come with a cost?

- Do we sacrifice sensitivity to improve specificity?
Performance of ECG Standards

“no change in sensitivity”

“100% sensitivity for SCD-associated conditions”

“all three criteria identified 98.1% of athletes with established HCM”

“all with 100% sensitivity for the pathological conditions detected”
Accuracy of the ECG for differential diagnosis between hypertrophic cardiomyopathy and athlete’s heart: comparison between the European Society of Cardiology (2010) and International (2017) criteria

Alessandro Zorzi,¹ Chiara Calore,¹ Riccardo Vio,¹ Antonio Pelliccia,² Domenico Corrado¹

BJSM; 2017

200 patients with HCM; 563 athletes

<table>
<thead>
<tr>
<th></th>
<th>ESC 2010</th>
<th>International Criteria 2017</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specificity</td>
<td>86.9%</td>
<td>95.9%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>95.5%</td>
<td>93%</td>
<td>0.47</td>
</tr>
</tbody>
</table>

2017 International Criteria improved the specificity and reduced the number of unnecessary investigations by 69%
Clinical questions when interpreting an athlete’s ECG

1. Is the ECG classified as:
   A. Normal – no further evaluation needed
   B. Abnormal – further evaluation needed

2. If the ECG is “abnormal”:
   A. What is the specific ECG abnormality?
   B. What is the appropriate next step in the evaluation?

3. Relevant clinical information:
   A. Age, race, and sex of athlete
   B. Asymptomatic and no family history of inherited cardiac disease or SCD?
## 6-Steps to ECG Interpretation in Athletes

<table>
<thead>
<tr>
<th>Where to look?</th>
<th>What to look for?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Precordial (V1-V6) then limb leads</strong> (aVF, aVL, II, I)</td>
<td>Q waves, ST depression, T wave inversion</td>
</tr>
<tr>
<td><strong>2. Precordial (V1-V6) then limb leads</strong> (aVF, aVL, II, I)</td>
<td>QRS morphology:</td>
</tr>
<tr>
<td></td>
<td>• pre-excitation (delta wave; short PR)</td>
</tr>
<tr>
<td></td>
<td>• bundle branch block</td>
</tr>
<tr>
<td></td>
<td>• conduction delay (QRS ≥140 ms)</td>
</tr>
<tr>
<td></td>
<td>• Brugada type 1</td>
</tr>
<tr>
<td><strong>3. Axis</strong> – limb leads I and II</td>
<td>QRS pos in I and II (leftward to -30°)</td>
</tr>
<tr>
<td></td>
<td>QRS neg in I and aVR, pos in II (rightward to 120°)</td>
</tr>
<tr>
<td><strong>4. Atrial enlargement</strong> – P wave in lead II</td>
<td>LAE: P &gt;120 ms → neg P wave in V1</td>
</tr>
<tr>
<td>(if needed V1)</td>
<td>RAE: P &gt;2.5 mm</td>
</tr>
<tr>
<td><strong>5. Rhythm strip</strong> – lead II or V5</td>
<td>QRS after every P wave</td>
</tr>
<tr>
<td></td>
<td>Narrow QRS vs PVCs</td>
</tr>
<tr>
<td><strong>6. QT interval</strong> – lead II or V5</td>
<td>QTc ≥470 ms males or ≥480 ms females</td>
</tr>
</tbody>
</table>
## Definitions: Normal ECG Findings

**Normal ECG findings in athletes**

These training-related ECG alterations are physiological adaptations to regular exercise, considered normal variants in athletes and do not require further evaluation in asymptomatic athletes with no significant family history.

<table>
<thead>
<tr>
<th>Normal ECG finding</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased QRS voltage</td>
<td>Isolated QRS voltage criteria for left (SV1 + RV5 or RV6 &gt;3.5 mV) or right ventricular hypertrophy (RV1 + SV5 or SV6 &gt;1.1 mV)</td>
</tr>
<tr>
<td>Incomplete right bundle branch block</td>
<td>rSR' pattern in lead V1 and a qRS pattern in lead V6 with QRS duration &lt;120 ms</td>
</tr>
<tr>
<td>Early repolarisation</td>
<td>J point elevation, ST elevation, J waves or terminal QRS slurring in the inferior and/or lateral leads</td>
</tr>
<tr>
<td>Black athlete repolarisation variant</td>
<td>J-point elevation and convex ('domed') ST segment elevation followed by T wave inversion in leads V1-V4 in black athletes</td>
</tr>
<tr>
<td>Juvenile T wave pattern</td>
<td>T wave inversion V1-V3 in athletes less than age less than 16</td>
</tr>
<tr>
<td>Sinus bradycardia</td>
<td>≥30bpm</td>
</tr>
<tr>
<td>Sinus arrhythmia</td>
<td>Heart rate variation with respiration: rate increases during inspiration and decreases during expiration</td>
</tr>
<tr>
<td>Ectopic atrial rhythm</td>
<td>P waves are a different morphology compared with the sinus P wave, such as negative P waves in the inferior leads ('low atrial rhythm')</td>
</tr>
<tr>
<td>Junctional escape rhythm</td>
<td>QRS rate is faster than the resting P wave or sinus rate and typically less than 100 beats/min with narrow QRS complex unless the baseline QRS is conducted with aberrancy</td>
</tr>
<tr>
<td>1° atrioventricular block</td>
<td>PR interval 200–400 ms</td>
</tr>
<tr>
<td>Mobitz type I (Wenckebach) 2° atrioventricular block</td>
<td>PR interval progressively lengthens until there is a non-conducted P wave with no QRS complex; the first PR interval after the dropped beat is shorter than the last conducted PR interval</td>
</tr>
</tbody>
</table>

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**International Criteria for ECG Interpretation in Athletes**

**Normal ECG Findings**
- Increased QRS voltage for LVH/RVH
- Incomplete AVB
- Early repolarisation
- ST segment deviation
- ST elevation followed by T wave inversion in V1-V4 in black athletes
- T wave inversion V1-V3 in patients ≥16 years old
- Sinus bradycardia
- Ectopic atrial or junctional rhythm
  - 1° AV block
  - Mobitz type I 2° AV block

**Borderline ECG Findings**
- Left axis deviation
- Left atrial enlargement
- Right axis deviation
- Right atrial enlargement
- Complete AVB

**Abnormal ECG Findings**
- T wave inversion
- ST segment depression
- Parachute Q waves
- Complete LVH
- QRS >150 ms duration
- P pulmonale
- Ventricular pre-excitation
- Protruded (CT) interval
- Brugada Type 3 pattern
- Profound sinus bradycardia <40 bpm
- PR interval ≥290 ms
- Mobitz type II AV block
- Mobitz type II 2° AV block
- 3° AV block
- 3° PVR
- Atrial tachyarrhythmia
- Ventricular arrhythmia

Further evaluation required in asymptomatic athletes with no family history of inherited cardiac disease or SCD.
Physiologic Cardiac Adaptation: ‘Athlete’s Heart’

- Increased Vagal Tone
  - Sinus bradycardia
  - Sinus arrhythmia
  - Early repolarization
  - 1° AVB
  - Mobitz Type I
  - 2° AVB

- Type of Sport
- Age/Sex
- Size
- Race/Genetics

- Enlarged Chamber Size
  - Wall thickness
  - Cavity dimension

- LVH voltage criteria
- Incomplete RBBB
Where to look?

1. Precordial (V1-V6) then limb leads (aVF, aVL, II, I)

What to look for?

Q waves, ST depression, T wave inversion
ECG from a 19 year old asymptomatic soccer player demonstrating voltage criteria for LVH (S-V1 + R-V5 > 35 mm). Note the absence of ST depression, T wave inversion, or pathologic Q waves. Increased QRS amplitude without other ECG abnormalities is a common finding in trained athletes and does not require additional testing.
ECG from a 29 year old asymptomatic soccer player demonstrating early repolarization (J-point and ST elevation) in II, III, aVF, V4-V6 (arrows) and tall, peaked T-waves (circles). These are common, training related findings in athletes and do not require more evaluation.
Incomplete Right Bundle Branch Block

- rSR’ pattern in lead V1
- QRS duration <120 ms
ECG demonstrates incomplete RBBB with rSR' pattern in V1 and QRS duration of < 120 ms. Incomplete RBBB is a common and normal finding in athletes and does not require additional evaluation.
ECG from a 24 year old asymptomatic black/African soccer player demonstrating J-point elevation, convex ('domed') ST elevation followed by T wave inversion in leads V1-V4 (circles). This is a normal repolarization pattern in black/African athletes.
ECG from a black/African athlete demonstrating voltage criterion for LVH, J-point elevation and convex (‘domed’) ST segment elevation followed by T wave inversion in V1-V4 (circles). This is a normal repolarization pattern in black athletes.
ECG from a 12 year old asymptomatic Caucasian female soccer player demonstrating the juvenile pattern of T wave inversion in leads V1-V3 (circles). This is a normal finding in athletes < 16 years of age.
Juvenile T Wave Inversion
Age <16 yo; Independent of race; TWI in V1-V3; Does not extend to V4

13 yo Caucasian female
15 yo Asian female

No further evaluation needed
# Definitions: Abnormal ECG Findings

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<th>ECG abnormality</th>
<th>Definition</th>
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<td>T wave inversion</td>
<td>≥1 mm in depth in two or more contiguous leads; excludes leads aVR, III and V1</td>
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<td>Anterior</td>
<td>V2-V4</td>
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<td>– excludes: black athletes with J-point elevation and convex ST segment elevation followed by TWI in V2-V4; athletes &lt; age 16 with TWI in V1-V3; and biphasic T waves in only V3</td>
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<tr>
<td>Lateral</td>
<td>I and AVL, V5 andor V6 (only one lead of TWI required in V5 or V6)</td>
</tr>
<tr>
<td>Inferolateral</td>
<td>II and aVF, V5-V6, I and AVL</td>
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<td>Inferior</td>
<td>II and aVF</td>
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<td>ST segment depression</td>
<td>≥0.5 mm in depth in two or more contiguous leads</td>
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<td>Pathological Q waves</td>
<td>Q/R ratio ≥0.25 or ≥40 ms in duration in two or more leads (excluding III and aVR)</td>
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<td>Complete left bundle branch block</td>
<td>QRS ≥120 ms, predominantly negative QRS complex in lead V1 (QS or rs) and upright notched or slurred R wave in leads I and V6</td>
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<td>Profound non-specific intraventricular conduction delay</td>
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<td>3° atrioventricular block</td>
<td>Complete heart block</td>
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### Table 1: International consensus standards for ECG interpretation in athletes: definitions of ECG criteria

#### Abnormal ECG findings in athletes

These ECG findings are unrelated to regular training or expected physiological adaptation to exercise, may suggest the presence of pathological cardiovascular disease and require further diagnostic investigation.

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<td>Complete heart block</td>
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### International Criteria for ECG interpretation in Athletes

- **Normal ECG Findings**
  - Young athlete
  - Normal latest ECG
  - No evidence of previous myocardial infarction
  - No evidence of previous arrhythmia
  - No evidence of previous electrical axis deviation
  - No evidence of left ventricular hypertrophy

- **Abnormal ECG Findings**
  - ST segment depression
  - Left ventricular hypertrophy
  - Right ventricular hypertrophy
  - Right bundle branch block
  - Left bundle branch block
  - Arrhythmias
  - Delayed repolarization
  - Pre-excitation syndromes

- **Additional ECG Findings**
  - Age > 40 years
  - History of hypertension or diabetes
  - Family history of sudden cardiac death
  - Personal history of myocardial infarction
  - Personal history of atrial fibrillation

- **No further evaluation required**
  - No further evaluation required
  - Normal ECG

- **Further evaluation required**
  - Normal ECG
  - Abnormal ECG
Abnormal ECG in a patient with hypertrophic cardiomyopathy. Note T wave inversion and ST segment depression in the inferolateral leads (arrows).
Abnormal ECG from a patient with hypertrophic cardiomyopathy. Note T wave inversions in I, aVL, and V4-V6 (red arrows), as well as ST segment depression in V4-V5 (black arrows).

Evaluation of inferolateral TWI

Additional testing to rule out cardiomyopathy

- Echo
- Cardiac MRI
- Holter + stress testing for ‘grey zone’ findings
Markedly abnormal ECG showing TWI $\geq 2$ mm in V4-V6. Note that the ST segment preceding TWI in V4-6 is flat or downsloping.
<table>
<thead>
<tr>
<th>ECG abnormality</th>
<th>Potential cardiac disease*</th>
<th>Recommended evaluation</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>T wave inversion in the lateral or inferolateral leads</td>
<td>HCM, DCM, LVNC, ARVC (with predominant left ventricular involvement), Myocarditis</td>
<td>Echocardiogram</td>
<td>Lateral or inferolateral T wave inversion is common in primary myocardial disease. Cardiac MRI should be a routine diagnostic test for this ECG phenotype and is superior to echocardiography for detecting apical HCM, left ventricular hypertrophy localised to the free lateral wall, ARVC with predominant left ventricular involvement and myocarditis. If cardiac MRI is not available, echocardiography with contrast should be considered as an alternative investigation for apical HCM in patients with deep T wave inversion in leads V5-V6. Consider family evaluation if available and genetic screening. Annual follow-up testing is recommended throughout athletic career in athletes with normal results.</td>
</tr>
<tr>
<td>T wave inversion isolated to the inferior leads</td>
<td>HCM, DCM, LVNC, Myocarditis</td>
<td>Echocardiogram</td>
<td>Consider cardiac MRI based on echocardiogram findings or clinical suspicion.</td>
</tr>
<tr>
<td>T wave inversion in the anterior leads¹</td>
<td>ARVC, DCM</td>
<td>Echocardiogram</td>
<td>The extent of investigations may vary based on clinical suspicion for ARVC and results from initial testing.</td>
</tr>
<tr>
<td>ST segment depression</td>
<td>HCM, DCM, LVNC, ARVC, Myocarditis</td>
<td>Echocardiogram</td>
<td>Consider cardiac MRI and additional testing based on echocardiogram findings or clinical suspicion.</td>
</tr>
<tr>
<td>Pathological Q waves</td>
<td>HCM, DCM, LVNC, Myocarditis, Prior myocardial infarction</td>
<td>Echocardiogram, Coronary artery disease risk factor assessment, Repeat ECG for septal (V1-V2) QS pattern; above investigations recommended if septal Q waves are persistent</td>
<td>Consider cardiac MRI (with perfusion study if available) based on echocardiogram findings or clinical suspicion. In the absence of cardiac MRI, consider exercise stress testing, dobutamine stress echocardiogram or a myocardial perfusion scan for evaluation of coronary artery disease in athletes with suspicion of prior myocardial infarction or multiple risk factors for coronary artery disease.</td>
</tr>
<tr>
<td>Complete left bundle branch block</td>
<td>DCM, HCM, LVNC, Sarcoïdosis, Myocarditis</td>
<td>Echocardiogram, Cardiac MRI (with stress perfusion study)³</td>
<td>A comprehensive cardiac evaluation to rule out myocardial disease should be considered.</td>
</tr>
</tbody>
</table>
**Evaluation of Lateral or Inferolateral TWI**

- Comprehensive evaluation to r/o cardiomyopathy
- Echocardiogram
- **Cardiac MRI should be a routine diagnostic test for this ECG phenotype**
  - Apical HCM, DCM, LVNC, AC with LV involvement, non-ischemic LV scar
- 24 hour ECG monitor + stress testing for ‘grey zone’ findings
Differences in LVH patterns between athletes with HCM and sedentary HCM patients.
Lateral T Wave Inversion

ECG in a 23 African-American male. TWI extending to V5 is considered abnormal. Only one lead of TWI required in V5 or V6.

**Evaluation of lateral TWI:**
- Echo required
- Cardiac MRI for TWI ≥2 mm, concurrent ST segment depression or other ECG abnormalities, or as indicated from Echo
- **Serial (annual) follow-up** (ECG + Echo) required; cardiac MRI for changes in ECG or Echo
Long-term Follow-up of Athletes with Markedly Abnormal ECGs

Pelliccia; NEJM 2008

Study Group; Normal Cardiac Imaging

9-year Follow-up

No Symptoms; No CV disease

81

70

6

Other CV Disease

Cardiomyopathies (HCM 3; ARVC 1; DCM 1)

6%

1 Sudden Death, 1 Cardiac Arrest

1 Study Group; Normal Cardiac Imaging

Sudden Death, Cardiac Arrest

6%
Serial Follow-up
19 yo African-American male, college basketball player

September 2008
Echo and CMR non-diagnostic

September 2010
CMR apical hypertrophy 20 mm with +LGE
Cardiac MRI Comparison
Midventricular Short Axis Views

Hypertrophy of interventricular septum over 2 years

Yearly repeat of ECG and cardiac imaging indicated for athletes with pathological lateral or inferolateral TWI and initial normal imaging studies.
21 yo Caucasian male with ECG demonstrating anterior T wave inversion (V1-V4) preceded by a non-elevated J-point and ST segment. Delayed S wave upstroke (≥ 55 ms) in V2 and low voltage (<5 mm) QRS complexes in limb leads I and aVL suggest possible ARVC.
Anterior T Wave Inversion

ECG from a patient with ARVC. Note pathological TWI in V1-V3 (arrows) preceded by a flat or downsloping ST segment and without J-point elevation. PVCs also present (circles).

**Evaluation of Anterior TWI**

*The extent of investigation may vary based on clinical suspicion for ARVC and results from initial testing.*

- Echo
- Cardiac MRI
- Exercise ECG test
- Minimum 24 hour ECG monitor
- Signal averaged ECG
ECG demonstrates TWI in the inferior leads II and aVF. This is an abnormal ECG and requires further evaluation (echocardiogram).
Normal or Abnormal?
Cardiology over-read: “Nonspecific T wave abnormality” and “Abnormal ECG”  
**Note:** This is a normal ECG. “Nonspecific T wave abnormality” is not part of the criteria. TWI in lead III is excluded. T wave flattening (II, V6) is also not part of the criteria. No further evaluation needed.
Pathologic Q Waves: Old Criteria
> 3 mm depth is out!
Pathologic Q Waves

**New Criteria:** Q/R ratio $\geq 0.25$ or Q wave $\geq 40 \text{ ms in duration}$
ECG of a young patient with dilated cardiomyopathy. Note inferior Q waves (II and aVF), poor R wave progression across the precordial leads with deep S waves in V1-V3, and a single premature ventricular complex (arrow). High degree AV block is also present.
Step 2: ECG Interpretation in Athletes

2. Precordial (V1-V6) then limb leads (aVF, aVL, II, I)

Where to look?
Where to look for?

2. Precordial (V1-V6) then limb leads (aVF, aVL, II, I)
QRS morphology: pre-excitation, BBB, conduction delay, Brugada type 1
ECG demonstrating the classic findings of Wolff-Parkinson-White pattern with a short PR interval (< 120 ms), delta wave (slurred QRS upstroke), and prolonged QRS (> 120 ms).
WPW classic findings:
- Short PR <120 ms
- Delta wave
- Wide QRS >120 ms

WPW additional findings:
- Large Q wave lead III
- Lack of Q wave in V6
- ST segment depression (not shown)
Ventricular Pre-excitation / Wolff-Parkinson-White pattern

- Short PR < 120 ms
- Delta waves
- Large Q wave lead III
- Lack of Q wave in V6
Evaluation of Ventricular Pre-excitation

• **Exercise ECG test**
  • Abrupt cessation of the delta wave (pre-excitation) denotes a low risk pathway
  • EP study should be considered if a low risk accessory pathway cannot be confirmed by non-invasive testing
  • Consider EP study for moderate to high intensity sports

• **Echocardiogram**
  • Association of pre-excitation with Ebstein’s anomaly and cardiomyopathy
Complete Right Bundle Branch Block

- 19 yo Caucasian male athlete with complete RBBB. The QRS duration is ≥120 ms with rSR’ pattern in V1 and S wave wider than R wave in V6.
- When found in isolation without other borderline or abnormal findings, and without other clinical markers of concern, complete RBBB does not require more investigation.
Complete RBBB with QRS Duration ≥ 140 ms = ABNORMAL

ECG showing complete RBBB with a QRS duration of 144 ms. Any conduction delay with QRS duration ≥ 140 ms requires further evaluation.
#StillLearning
Step-3: ECG Interpretation in Athletes

Where to look? | What to look for?
---|---
3. Axis – limb leads I and II | QRS pos in I and II (leftward to -30°)
| QRS neg in I and aVR (rightward to 120°)
Step-4: ECG Interpretation in Athletes

Where to look? | What to look for?
---|---
4. Atrial enlargement – P wave in lead II (if needed V1) | LAE: P >120 ms → neg P wave in V1
RAE: P >2.5 mm
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

Borderline ECG Findings
- Left axis deviation
- Left atrial enlargement
- Right axis deviation
- Right atrial enlargement
- Complete RBBB

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

No further evaluation required in asymptomatic athletes with no family history of inherited cardiac disease or SCD

Further evaluation required to investigate for pathologic cardiovascular disorders associated with SCD in athletes
ECG demonstrates abnormal left axis deviation defined as frontal plane QRS axis of less than -30°. The QRS is positive in lead I and negative in aVF and lead II. The QRS axis shown here is about -70°.
ECG demonstrates left atrial enlargement, defined as a prolonged P wave duration of >120 ms in leads I or II with negative portion of the P wave ≥1 mm in depth and ≥40 ms in duration in lead V1.
≥ 2 Borderline Findings = Abnormal ECG
• Complete RBBB • LAD • RAE

Evaluation
• Echocardiogram
• Consider additional testing based on clinical suspicion
Step-5: ECG Interpretation in Athletes

Where to look? | What to look for?
---|---
5. Rhythm strip – lead II or V5 | QRS after every P wave
 | Narrow QRS vs PVCs
Mobitz Type I (Wenckebach) 2° AV Block

- Mobitz Type I (Wenckebach) 2° AV block is demonstrated by progressively longer PR intervals until there is a non-conducted P-wave and no QRS.
- The first PR interval after the dropped beat is shorter than the last conducted PR interval prior to the dropped beat.
Mobitz Type II 2\(^{nd}\) Degree AV Block

- P waves with loss of conduction and no QRS complex (arrows)
- No PR prolongation in the beats prior, nor PR shortening in the beats after (i.e. not Mobitz type I)

Evaluation to rule out myocardial or conduction disease

- Echocardiogram
- Minimum 24 hour ECG monitor
- Exercise ECG test
- Consider cardiac MRI based on initial findings
Step-6: ECG Interpretation in Athletes

**Where to look?**
6. QT interval – lead II or V5

**What to look for?**
QTc ≥470 ms males or ≥480 ms females
Long QT Syndrome?

Normal ECG
• QTc is normal
• Don’t include the U wave in anterior precordial leads!
  • “Teach-the-tangent” or “Avoid-the-tail” method for manual measurement of the QT interval

No further evaluation needed
This figure illustrates the “Teach-the-Tangent” or “Avoid-the-Tail” method for manual measurement of the QT interval. A straight line is drawn on the downslope of the T wave to the point of intersection with the isoelectric line. The U wave is not included.

- **Bazett’s formula**: $QTc = QT/\sqrt{RR}$
  - Inaccurate at heart rates < 50 or > 90 bpm
  - QT interval will equal the QTc at a heart rate of 60 bpm
- Use **lead II or V5** where the end of the T wave is readily delineated
- Abnormal QTc is considered ≥470 ms in males and ≥480 ms in females
Normal or Abnormal?

14 yo Caucasian female elite soccer player
Abnormal ‘notched’ T Wave morphology suggests LQT-2

Average QT interval ~500 ms
EVALUATION OF A PROLONGED QTc

This alone is NOT a diagnosis of LQTS

QTc ≥ 470 ms males
QTc ≥ 480 ms females

1. Repeat resting ECG on separate day
2. Review for QT prolonging medications

QTc ≥ 500 ms

Possible congenital LQTS
Referral to a heart rhythm specialist or sports cardiologist
- QT interval duration and morphology (notching)
- Laboratory (electrolyte) testing
- Family screening (ECGs of first-degree relatives)
- Exercise ECG test (paradoxical prolongation of the QTc during the recovery phase)
- Genetic testing (confirmatory mutation)

QTc < 470 ms males
QTc < 480 ms females
AND
No concerning symptoms or family history

No further evaluation

• SYMPTOMS: exercise, emotion, or auditory triggered syncope or seizure
• FAMILY HX: unexplained syncope, seizures, SCA/D, drowning or MVA
ECG Screening – Getting Started

• **Best practices:**
  1) **Pre-screening planning** and coordination - team physicians, athletic trainers, cardiology consultants, and athletic administrators
  2) Accurate **ECG lead placement** performed by trained personnel
  3) **ECG interpretation** with modern standards that distinguish physiological cardiac remodeling from findings suggestive of underlying cardiac pathology
  4) Standards for ECG interpretation should be reviewed and agreed upon
  5) **Cardiology oversight** and resources to assist with the secondary investigation of ECG abnormalities
  6) Avenues for prompt **secondary cardiac testing** and consultation for ECG abnormalities should be established
Evolution of ECG Interpretation Standards

Figure 1: Percentage of Abnormal ECGs in Adolescents According to Four ECG Criteria by Ethnicity

ESC (2010)
12.9%
16.2%

Seattle (2013)
4.2%
5.9%

Refined (2014)
2.8%
5.9%

International (2017)
1.7%
3.6%

ESC= European Society of Cardiology; white athlete depicted by grey figure; black athlete depicted by black figure

Malhotra et al. BJSM 2019
Evolution of ECG Interpretation Standards


False Positive

Sensitivity
New modules on BMJ Learning

ECG interpretation in athletes

Written by international experts in sports cardiology, covering:
- ECG interpretation in athletes: identify your learning needs
- Recognizing physiologic adaptations in athletes
- Abnormal ECG findings in athletes: recognizing changes suggestive of cardiomyopathy
- Abnormal ECG findings in athletes: recognizing changes suggestive of primary electrical disease
- ECG interpretation in athletes: test your knowledge

Register for your free BMJ Learning account now at learning.bmj.com/ECGathlete
1. Basic ECG Interpretation in Athletes
2. Normal ECG Findings in Athletes
3. ECG Abnormalities in Cardiomyopathy
4. ECG Abnormalities in Primary Electrical Disease
5. ECG Interpretation Challenges & Common Pitfalls
6. ECG Interpretation Challenges & Common Pitfalls

To access the free ECG training modules, go to: www.uwsportscardiology.org/E-Academy

The Center for Sports Cardiology at the University of Washington in collaboration with the Australasian College of Sport and Exercise Physicians are extremely excited to offer open access worldwide to a new collection of six online ECG training modules. These are based on the ‘International criteria’ and the latest consensus recommendations for ECG interpretation in athletes.
ECG INTERPRETATION IN ATHLETES
uwsportscardiology.org/e-academy

MODULE 1
Basic ECG interpretation in athletes

MODULE 2
Normal physiologic ECG findings in athletes

MODULE 3
ECG abnormalities in cardiomyopathy

MODULE 4
ECG abnormalities in primary electrical disease

MODULE 5
ECG interpretation challenges and pitfalls

MODULE 6
Advanced ECG interpretation in athletes
HYPERTROPHIC CARDIOMYOPATHY
Normal or Abnormal?

ECG in a 20-yo black athlete showing pathological inferolateral TWI in V5-V6, II and aVF. TWI in V5-V6 is always considered abnormal. TWI in V3-V4 represents the black athlete repolarization variant.

Evaluation of Inferolateral TWI

Additional testing to rule out cardiomyopathy
- Echo
- Cardiac MRI
- Holter + stress testing for ‘grey zone’ findings
- If initial studies are non-diagnostic → serial (annual) follow-up with ECG + Echo (at minimum); cardiac MRI for changes in ECG or Echo
TAKE HOME POINTS

1. Follow the International Criteria recommendations for ECG interpretation and the secondary evaluation of ECG abnormalities
2. Consider “6-steps” to accurate ECG interpretation in athletes
3. Lateral or inferolateral TWI requires a contrast-enhanced CMR
4. Serial cardiac imaging is required for athletes with markedly abnormal ECGs and normal cardiac imaging
Thank You

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https://uwsportscardiology.org/e-academy/