Applying the International Criteria for ECG Interpretation in Athletes to a pre-participation screening program

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Background – “Athlete’s heart”

- Increased Vagal Tone
- Enlarged Chamber Size
- LVH voltage criteria
- Incomplete RBBB

- Type of Sport
- Age
- Gender
- Size
- Race/Genetics
- Wall thickness
- Early dimension

Ultimate question

• In the context of a highly trained athlete, which screening ECG changes can be considered normal manifestations of the “athlete’s heart,” and which should be considered pathologic?
“International Criteria”

- Asymptomatic athletes age 12-35 years
- **Endorsed** by 17 international sports medicine and cardiology societies
- **Clear guide** to the evaluation of ECG abnormalities
- Sports medicine and cardiology looking through the same lens

Does modifying the criteria come with a cost?

- Do we sacrifice sensitivity to increase 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”

<table>
<thead>
<tr>
<th>False</th>
<th>Positive Rate</th>
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<tr>
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Performance of ECG criteria

Accuracy of the ECG for differential diagnosis between hypertrophic cardiomyopathy and athlete’s heart: comparison between the European Society of Cardiology (ESC) 2010 and International (2017) criteria

<table>
<thead>
<tr>
<th></th>
<th>ESC 2010</th>
<th>International Criteria 2017</th>
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<tbody>
<tr>
<td>Specificity</td>
<td>86.9%</td>
<td>95.5%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>95.5%</td>
<td>93%</td>
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2017 International Criteria improved the specificity and reduced the number of unnecessary investigations by 69% (from 1:8 athletes to 1:24 athletes)

International Criteria for ECG Interpretation in Athletes

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 findings associated with HCM in athletes

Normal ECG Findings
- Increased QRS voltage for LVH or RVH
- Outpouring T wave
- Early repolarization (ST elevation)
- RV deviation followed by T wave inversion
- T wave inversion in 0.5 V c 16 years old
- Sinus bradycardia or arrhythmia
- P wave or junctional rhythm
- "S" wave
- Delta Type II in blacks

Borderline ECG Findings
- Left atrial enlargement
- Left ventricular hypertrophy
- Right atrial enlargement
- Right ventricular hypertrophy
- Complete RBBB

Abnormal ECG Findings
- Right Bundle Branch Block
- Left Bundle Branch Block
- Complete atrioventricular block
- Sinus bradycardia or arrhythmia
- Mobitz Type I 2° AV block
- Mobitz Type II 2° AV block
- 3° AV block
- Atrial tachycardia
- Ventricular arrhythmia
- Prolonged corrected QT interval
- Brugada Type 1 pattern
- Periastolic Q waves
- ST segment depression
- ST segment elevation
- T wave inversion
- Pathologic Q waves
- Complete LBBB
- Sinus bradycardia <30 bpm
- PR interval ≥ 400 ms
- Mobitz Type II 2° AV block
- ≥ 2 PVCs
- Atrial fibrillation
- Ventricular fibrillation
- Ventricular arrhythmia
- Hypertrophic cardiomyopathy
- Necrotic or fibrotic myocardial scar
- Vascular or valvular abnormalities

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 findings associated with HCM in athletes
Clinical questions when interpreting ECGs

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 evaluation?

3) Relevant clinical information
   A. Age, race, and sex of athlete
   B. Asymptomatic and no family history of inherited cardiac disease or SCD?

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**International Criteria for ECG Interpretation in Athletes**

**Normal ECG Findings**
- Increased QRS voltage
- Incomplete RBBB
- Early repolarization
- ST elevation followed by T wave inversion
- Sinus bradycardia
- Ectopic atrial or junctional rhythm
- 1° AV block
- Mobitz Type I 2° AV block

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

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

Further evaluation required to investigate for pathologic cardiovascular disorders associated with SCD in athletes.

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

Further evaluation required to investigate for pathologic cardiovascular disorders associated with SCD in athletes.
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.

Incomplete Right Bundle Branch Block

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.

Early Repolarization

ECG from a 24-year-old asymptomatic black/African soccer player demonstrating J-point and convex ('domed') ST elevation followed by T wave inversion in leads V1-V4 (circles). This is a normal repolarization pattern in black/African athletes.

Black Athlete Repolarization Variant
**Black Athlete Repolarization Variant:**

Confined to Leads V1-V4

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 V3-V4 (circles). This is a normal repolarization pattern in black athletes.

**Juvenile T Wave Inversion**

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 yr; Independent of race; TWI in V2-V3; Does not extend to V4

23 yr Caucasian female 15 yr Asian female

No further evaluation needed
A 28 year old Caucasian male demonstrating a junctional escape rhythm (red arrows). Note the constant RR interval between beats.

**Junctional Escape Rhythm**

ECG shows 1° AV block (PR interval >200 ms). The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. In this ECG tracing, the PR interval is constant from beat to beat and measures 300 ms.

**1° Atrioventricular Block**

ECG shows 1° AV block (PR interval >200 ms). The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. In this ECG tracing, the PR interval is constant from beat to beat and measures 300 ms.

**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 I (Wenckebach) 2° AV Block**

**Normal ECG Findings**
- Increased QRS voltage for LVH or RVH
- Incomplete RBBB
- Early repolarization/ST segment elevation
- ST elevation followed by T wave inversion in V1-V4 in black athletes
- 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
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- Profound sinus bradycardia <30 bpm
- PR interval ≥ 400 ms
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- 3° AV block
- ≥ 2 PVCs
- Atrial tachyarrhythmias
- Ventricular arrhythmias

**International Criteria for ECG Interpretation in Athletes**

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.

- N=2533 athletes: no athlete with isolated left or right axis deviation or atrial enlargement showed evidence of cardiomyopathy
- N=171 patients with HCM: co-existing ECG abnormalities present in 89% with axis deviation or atrial enlargement
Left Atrial Enlargement

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.

Left Axis Deviation

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°.

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.
Definitions:

Abnormal ECG findings 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).

Inferolateral T Wave Inversion and ST Depression

Evaluation of inferolateral TWI
Additional testing to rule out cardiomyopathy
- Echo
- Cardiac MRI
- Holter + stress testing for 'grey zone' findings

Inferolateral T Wave Inversion and ST Depression

Lateral T Wave Inversion

Markedly abnormal ECG showing TWI ≥ 2 mm in V4-V6. Note that the ST segment preceding TWI in V4-V6 is flat or downsloping.

Table 1: Evaluation of ECG abnormalities

<table>
<thead>
<tr>
<th>TWI (mm)</th>
<th>Echo</th>
<th>Cardiac MRI</th>
<th>Holter + stress testing</th>
</tr>
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<tbody>
<tr>
<td>TWI 1</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>TWI 2</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>TWI 3</td>
<td>+</td>
<td>+</td>
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</tbody>
</table>

Note: TWI ≥ 2 mm in V4-V6 requires additional testing to rule out cardiomyopathy.
Evaluation of Lateral or Inferolateral TWI

Comprehensive evaluation to rule out cardiomyopathy
- Echocardiogram
- Cardiac MRI should be a routine diagnostic test for this ECG phenotype
- 24 hour ECG monitor + stress testing for ‘grey zone’ findings

Apical HCM

Lateral T Wave Inversion in V5

Evaluation of lateral TWI in V5 (not V6)
- Echo required
- Cardiac MRI for TWI ≥ 2 mm, concurrent ST segment depression or other ECG abnormalities, or as indicated from Echo

ECG in a 18 yo African-American male. TWI extending to V5 is considered abnormal. Only one lead of TWI required in V5 or V6.

The “Markedly Abnormal” ECG

ECG from a patient with HCM demonstrating QRS voltage criterion for LVH in association with deep T wave inversion and ST segment depression predominantly in the lateral leads (I, aVL, V4-V6), voltage criterion for left and right atrial enlargement, and left axis deviation.
Long-term Follow-up of Athletes with Markedly Abnormal ECGs

Pelliccia; NEJM 2008

Study Group:
Normal Cardiac Imaging

81

9-year Follow-up

70

No Symptoms; No CV disease

6

6%

1 Sudden Death, 1 Cardiac Arrest

5

Other CV Disease (HCM 3; ARVC 1; DCM 1)

Serial Follow-up
Asian-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.
Normal or Abnormal?

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

A. Physiologic
- Black athlete repolarization variant

B. Pathologic
- T wave inversion

Physiologic (A) and pathologic T wave inversion (B). Panel A demonstrates physiologic repolarization in a black athlete with TWI in V1-V4 preceded by J-point and convex-dome ST segment elevation (green circles). Panel B demonstrates pathologic TWI in V2-V6 with absent J-point elevation and a downsloping ST segment (red circles).

Anterior T Wave Inversion

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 in V2 and low voltage (<5 mm) QRS complexes in limb leads I and aVL suggest possible ARVC.
Anterior T Wave Inversion

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 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).

Epsilon Wave

Definition

2010 ARVC/D Task Force Criteria
"Reproducible low amplitude signal between end of QRS complex and onset of the T wave in the right precordial leads (V1 to V3)."

2017 Athlete International Criteria
"Distinct low amplitude signal (small positive deflection or notch) between the end of the QRS complex and onset of the T wave in leads V1-V3."

Epsilon waves are typically a manifestation of more advanced disease and unlikely to be an isolated ECG finding. In patients with ARVC that express an epsilon wave:
- 99% also manifest TWI in the right precordial leads
- 100% have a delayed S wave upstroke (prolonged terminal activation duration) >55 ms from the nadir of the S wave to the end of the QRS complex
- Thus, a suspected epsilon wave should prompt further evaluation for other ECG findings that are diagnostic for ARVC (TWI, delayed S wave upstroke, low limb lead voltage)
Inferior T Wave Inversion

Normal or Abnormal?

18 yo Caucasian male with TWI in leads III and aVF. Lead III is excluded (need 2 contiguous leads). In the absence of symptoms or other clinical markers of concern, this is a normal ECG and no further evaluation is needed.

Inferior T Wave Inversion

ECG demonstrates TWI in the inferior leads II and aVF. This is an abnormal ECG and requires further evaluation (echocardiogram).

Pathologic Q Waves

New Criteria: Q/R ratio ≥ 0.25 or ≥ 40 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.

Pathologic Q Waves

- Q/R ratio ≥ 0.25 or ≥ 40 ms in duration

**Evaluation of Pathologic Q Waves**

**Echocardiogram**
- Consider cardiac MRI (with perfusion study) based on echocardiogram findings and clinical suspicion

**Coronary artery disease risk factor assessment**
- Consider exercise stress testing, dobutamine echo, or myocardial perfusion scan in athletes >30 yo or if multiple risk factors for CAD are present

Repeat ECG for septal (V5-V2) QS pattern
- “pseudo-septal” infarct pattern from high lead misplacement
Anterior Q Waves V1-V2 / QS Pattern

ECG in a 22 y/o African American male. Anterior Q waves can be from incorrect high lead placement of V1-V2 (ie "pseudo-septal" infarct).

Evaluation of Anterior Q waves
1) Repeat ECG
2) If Q waves persist → Echocardiogram
3) CAD risk assessment
   - Stress testing for multiple risk factors or age >30 years

Anterior Q Waves?

Repeat ECG in same athlete shows RS in V2 (arrows). This suggests QS pattern was lead placement issue. No further evaluation needed.
ECG demonstrating the classic findings of WPW with a short PR interval (<120 ms), delta wave (slurred QRS upstroke), and prolonged QRS (>120 ms).

Ventricular Pre-excitation / Wolff-Parkinson-White

17 yr asymptomatic female with negative family history. ECG demonstrates a short PR interval and delta waves (black arrows). Other findings suggestive of WPW include a large Q wave in lead III (red circle), absence of a Q wave in V6 (blue arrowhead), and ST-segment depression in V5-V6 and lead II (red arrows).

Ventricular Pre-excitation / WPW Pattern
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

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**Long QT Syndrome?**

Normal ECG
- QT 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

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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.
Abnormal ECG = Temporary Restriction?

Temporary restriction from athletic activity should be considered for athletes with abnormal ECGs, especially when there is high clinical suspicion for pathologic cardiac disease, until secondary investigations are completed.

Conditional clearance for sports participation pending further evaluation can be considered on a case-by-case basis.
Thank you!

• Questions or clarifications?

Please feel free to email me:
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