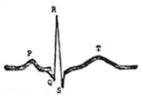
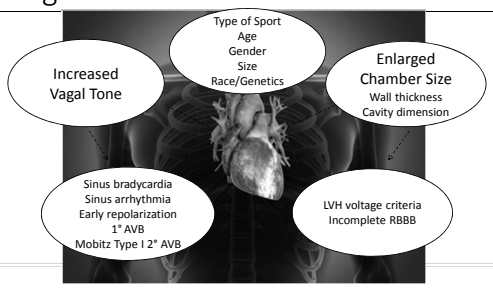


Applying the International Criteria for ECG Interpretation in Athletes to a pre-participation screening program

DAVE SIEBERT, MD, CAQSM
ASSISTANT PROFESSOR
DEPARTMENT OF FAMILY MEDICINE
UNIVERSITY OF WASHINGTON
UW HUSKY TEAM PHYSICIAN

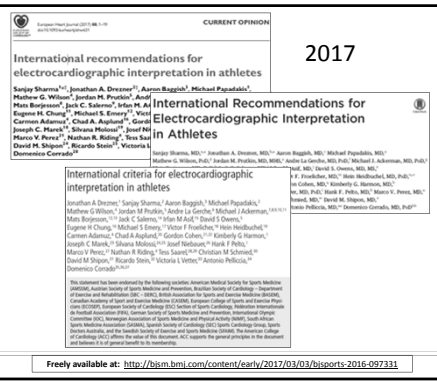
2018 COXHEALTH SPORTS MEDICINE CONFERENCE
SPRINGFIELD, MISSOURI, USA
JUNE 23, 2018

Background – "Athlete's heart"



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**?



2017

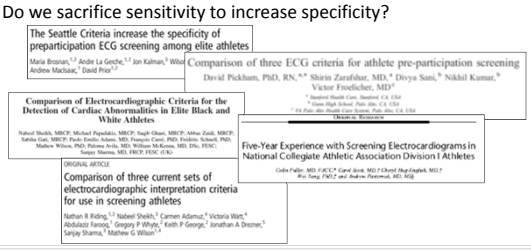
Freely available at: http://bjsm.bmj.com/content/early/2017/03/03/bjsports-2016-097331

"International Criteria"

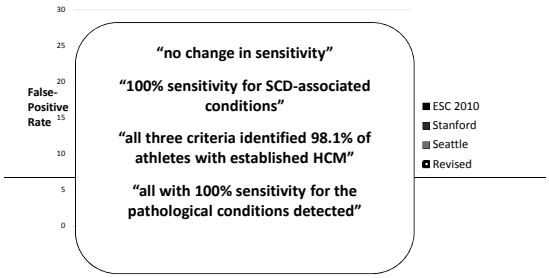
- Asymptomatic athletes age 12-35 years
- **Endorsed** by 17 international sports medicine and cardiology societies
- **Clear guide** to the evaluation of ECG abnormalities
- Sports medicine and cardiology looking through the same lens

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"

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 (2010) and International (2017) criteria

Alessandro Zorzi,[1] Chiara Calore,[1] Riccardo Vio,[1] Antonio Pelliccia,[2] Domenico Corrado[1]

BJSM; 2017

	ESC 2010	International Criteria 2017	
Specificity	**86.9%**	**95.9%**	**p<0.001**
Sensitivity	**95.5%**	**93%**	**p=0.47**

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

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

In isolation

2 or more

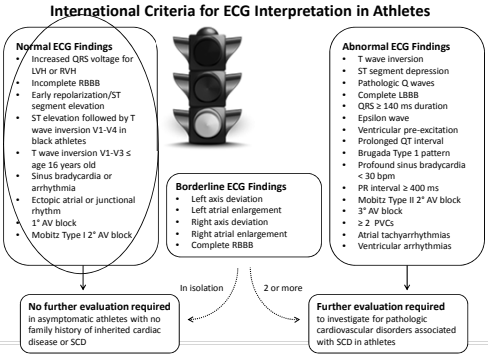
No further evaluation required in asymptomatic athletes with no family history of inherited cardiac disease or SCD

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

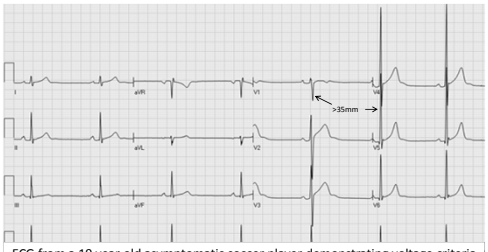
Clinical questions when interpreting ECGs

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?

International Criteria for ECG Interpretation in Athletes

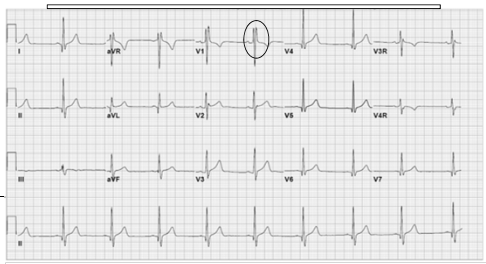


Isolated Increased QRS Voltage



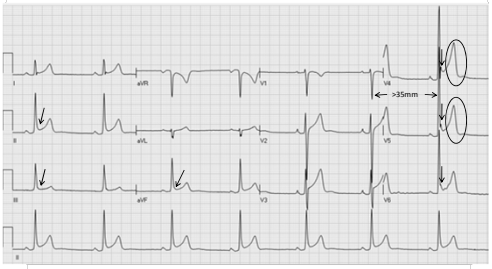
ECG from a 19 year old asymptomatic soccer player demonstrating voltage criteria for LVH (S-V1 + R-V5 > 35 mm). Note the absence of ST depression, T wave inversion, or pathologic Q waves. Increased QRS amplitude without other ECG abnormalities is a common finding in trained athletes and does not require additional testing.

Incomplete Right Bundle Branch Block



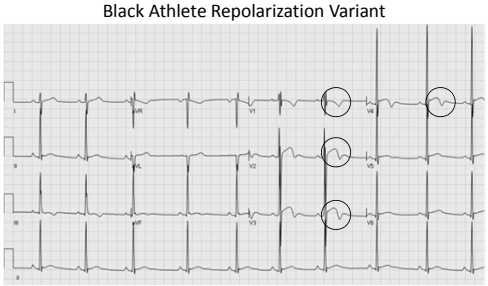
ECG demonstrates incomplete RBBB with rSR' pattern in V1 and QRS duration of <120 ms. Incomplete RBBB is a common and normal finding in athletes and does not require additional evaluation.

Early Repolarization



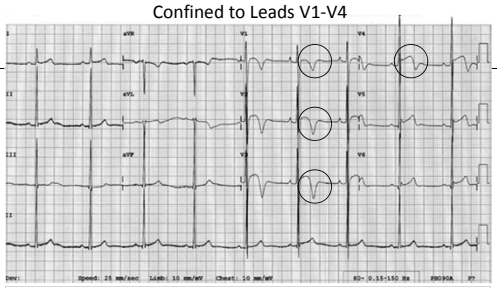
ECG from a 29 year old asymptomatic soccer player demonstrating early repolarization (J-point and ST elevation) in II, III, aVF, V4-V6 (arrows) and tall, peaked T-waves (circles). These are common, training related findings in athletes and do not require more evaluation.

Black Athlete Repolarization Variant



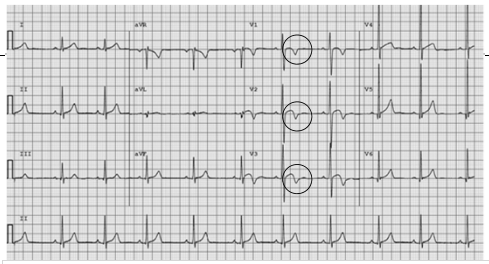
ECG from a 24 year old asymptomatic black/African soccer player demonstrating J-point and convex ('domed') ST elevation followed by T wave inversion in leads V1-V4 (circles). This is a normal repolarization pattern in black/African athletes.

Black Athlete Repolarization Variant: 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 V1-V4 (circles). This is a normal repolarization pattern in black athletes.

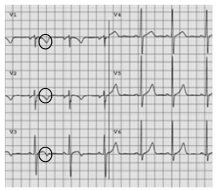
Juvenile T Wave Inversion



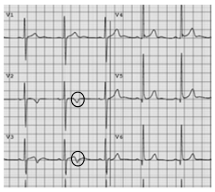
ECG from a 12 year old asymptomatic Caucasian female soccer player demonstrating the juvenile pattern of T wave inversion in leads V1-V3 (circles). This is a normal finding in athletes <16 years of age.

Juvenile T Wave Inversion

Age <16 yo; Independent of race; TWI in V1-V3; Does not extend to V4



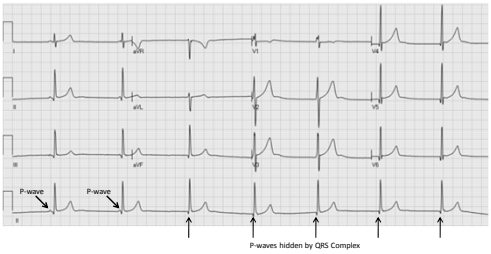
13 yo Caucasian female



15 yo Asian female

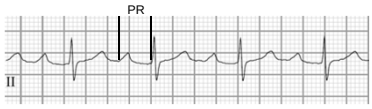
No further evaluation needed

Junctional Escape Rhythm



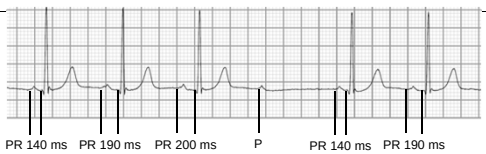
A 28 year old Caucasian male demonstrating a junctional escape rhythm (red arrows). Note the constant RR interval between beats.

1° Atrioventricular Block



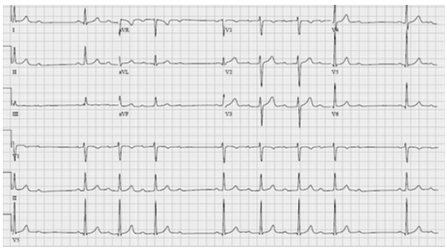
ECG shows 1° AV block (PR interval >200 ms). The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. In this ECG tracing, the PR interval is constant from beat to beat and measures 300 ms.

Mobitz Type I (Wenckebach) 2° AV Block

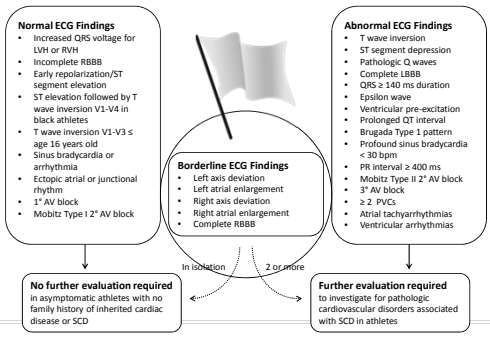


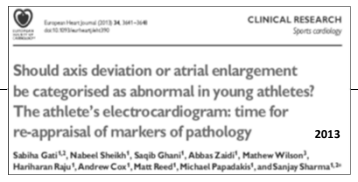
- Mobitz Type I (Wenckebach) 2° AV block is demonstrated by progressively longer PR intervals until there is a non-conducted P-wave and no QRS.
- The first PR interval after the dropped beat is shorter than the last conducted PR interval prior to the dropped beat

Mobitz Type I (Wenckebach) 2° AV Block



International Criteria for ECG Interpretation in Athletes



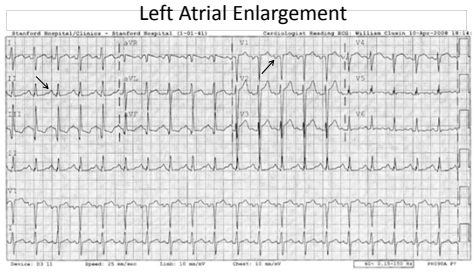

CLINICAL RESEARCH
Sports cardiology

Should axis deviation or atrial enlargement be categorised as abnormal in young athletes? The athlete's electrocardiogram: time for re-appraisal of markers of pathology **2013**

Sabiha Gati[1,2], Nabeel Sheikh[1], Saqib Ghani[1], Abbas Zaidi[1], Mathew Wilson[1], Hariharan Raju[1], Andrew Cox[1], Matt Reed[1], Michael Papadakis[1], and Sanjay Sharma[1,2]*

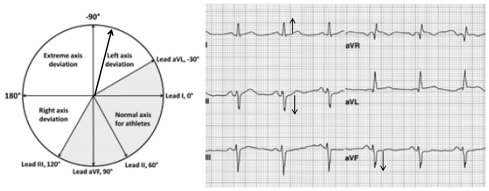
- N=2533 athletes: **no athlete with isolated left or right axis deviation or atrial enlargement showed evidence of cardiomyopathy**
- N=171 patients with HCM: co-existing ECG abnormalities present in 89% with axis deviation or atrial enlargement

Left Atrial Enlargement



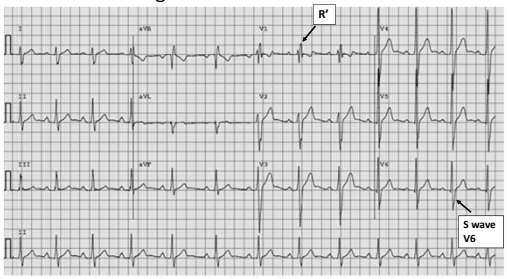
ECG demonstrates left atrial enlargement, defined as a prolonged P wave duration of >120 ms in leads I or II with negative portion of the P wave ≥1 mm in depth and ≥40 ms in duration in lead V1

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.

International Criteria for ECG Interpretation 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

In isolation

2 or more

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

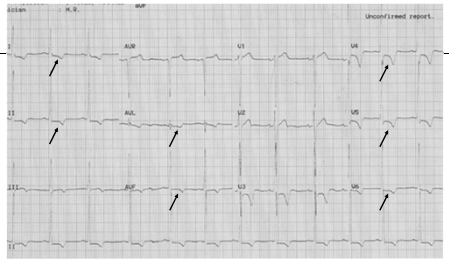
Definitions

Table 1 International consensus standards for ECG interpretation in athletes: definitions of ECG criteria

ECG abnormality	Definition
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.*	
T wave inversion	≥1 mm in depth in two or more contiguous leads; excludes leads aVR, III and V1
► Anterior	► V2-V4 – excludes: black athletes with J-point elevation and convex ST segment elevation followed by TWI in V2-V4; athletes < age 16 with TWI in V1-V3; and biphasic T waves in only V3
► Lateral	► I and AVL, V5 and/or V6 (only one lead of TWI required in V5 or V6)
► Inferolateral	► II and aVF, V5-V6, I and AVL
► Inferior	► II and aVF
ST segment depression	≥0.5 mm in depth in two or more contiguous leads
Pathological Q waves	Q/R ratio ≥0.25 or ≥ 40 ms in duration in two or more leads (excluding III and aVR)
Complete left bundle branch block	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
Profound non-specific intraventricular conduction delay	Any QRS duration ≥ 140 ms
Epsilon wave	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
Ventricular pre-excitation	PR interval <120 ms with a delta wave (slurred upstroke in the QRS complex) and wide QRS (≥ 120 ms)
Prolonged QT interval*	QTc ≥ 470 ms (male) QTc ≥ 480 ms (female) QTc ≥ 500 ms (marked QT prolongation)
Brugada type 1 pattern	Coved pattern: initial ST elevation ≥2 mm (high take-off) with downsloping ST segment elevation followed by a negative symmetric T wave in ≥ 1 leads in V1-V3
Profound sinus bradycardia	<30 beats per minute or sinus pauses ≥ 3 s
Profound 1° atrioventricular block	≥ 400 ms
Mobitz type II 2° atrioventricular block	Intermittently non-conducted P waves with a fixed PR interval
3° atrioventricular block	Complete heart block

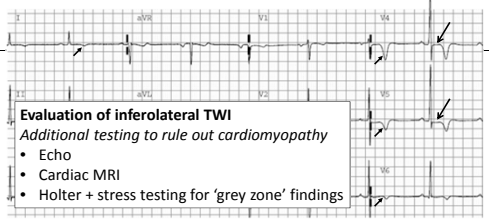
Understand the precise definition of ECG abnormalities

Inferolateral T Wave Inversion and ST Depression



Abnormal ECG in a patient with hypertrophic cardiomyopathy. Note T wave inversion and ST segment depression in the inferolateral leads (arrows).

Inferolateral T Wave Inversion and ST Depression



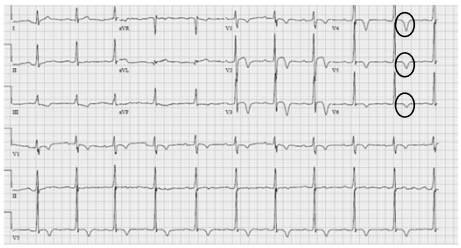
Evaluation of inferolateral TWI

Additional testing to rule out cardiomyopathy

- Echo
- Cardiac MRI
- Holter + stress testing for 'grey zone' findings

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).

Lateral T Wave Inversion



Markedly abnormal ECG showing TWI ≥2 mm in V4-V6. Note that the ST segment preceding TWI in V4-6 is flat or downsloping.

Table 2 Evaluation of ECG abnormalities in athletes

ECG abnormality	Potential cardiac disease*	Recommended evaluation†	Considerations
T wave inversion in the lateral or inferolateral leads	HCM DCM LVNC ARVC (with predominant left ventricular involvement) Myocarditis	Echocardiogram Cardiac MRI Exercise ECG test Minimum 24 hours ECG monitor	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 localized 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.
T wave inversion isolated to the inferior leads	HCM DCM LVNC Myocarditis	Echocardiogram	Consider cardiac MRI based on echocardiogram findings or clinical suspicion.
T wave inversion in the anterior leads‡	ARVC DCM	Echocardiogram Cardiac MRI Exercise ECG test Minimum 24 hours ECG monitor Signal-averaged ECG	The extent of investigations may vary based on clinical suspicion for ARVC and results from initial testing.
ST segment depression	HCM DCM LVNC ARVC Myocarditis	Echocardiogram	Consider cardiac MRI and additional testing based on echocardiogram findings or clinical suspicion.
Pathological Q waves	HCM DCM LVNC Myocarditis Prior myocardial infarction	Echocardiogram Coronary artery disease risk factor assessment Repeat ECG for septal (V1-V2) Q5 pattern; above investigations recommended if septal Q waves are persistent	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.
Complete left bundle branch block	DCM HCM LVNC Sarcoidosis Myocarditis	Echocardiogram Cardiac MRI (with stress perfusion study)§	A comprehensive cardiac evaluation to rule out myocardial disease should be considered.

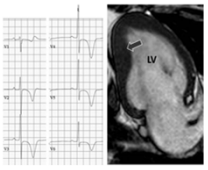
Evaluation of Lateral or Inferolateral TWI

Comprehensive evaluation to r/o cardiomyopathy

Echocardiogram

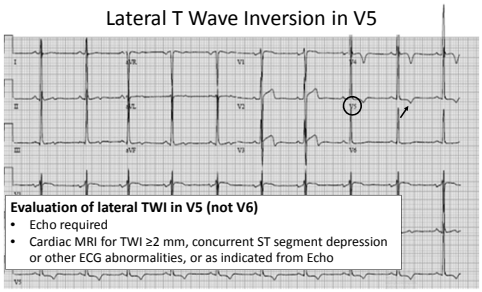
Cardiac MRI should be a routine diagnostic test for this ECG phenotype

24 hour ECG monitor + stress testing for 'grey zone' findings



Apical HCM

Lateral T Wave Inversion in V5

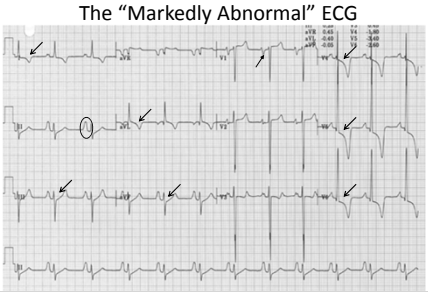


Evaluation of lateral TWI in V5 (not V6)

- 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

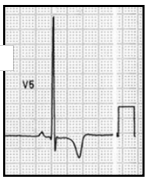


ECG from a patient with HCM demonstrating QRS voltage criterion for LVH in association with deep T wave inversion and ST segment depression predominantly in the lateral leads (I, aVL, V4-V6), voltage criterion for left and right atrial enlargement, and left axis deviation.

Long-term Follow-up of Athletes with Markedly Abnormal ECGs

Pelliccia; *NEJM* 2008

Study Group; Normal Cardiac Imaging: ***81***



9-year Follow-up

No Symptoms; No CV disease: ***70***

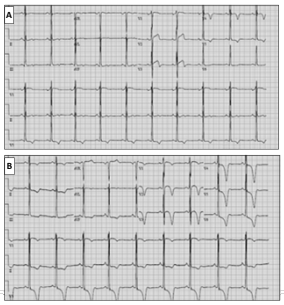
6%

6 Other CV Disease

5 Cardiomyopathies (HCM 3; ARVC 1; DCM 1) → 1 Sudden Death, 1 Cardiac Arrest

Serial Follow-up

19 yo African-American male, college basketball player

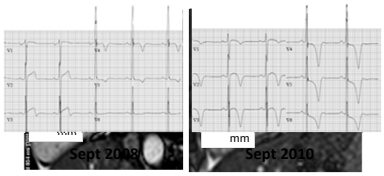


September 2008
Echo and CMR non-diagnostic

September 2010
CMR apical hypertrophy 20 mm with +LGE

Cardiac MRI Comparison

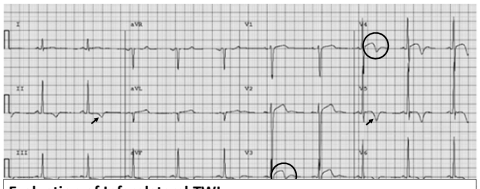
Midventricular Short Axis Views



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.

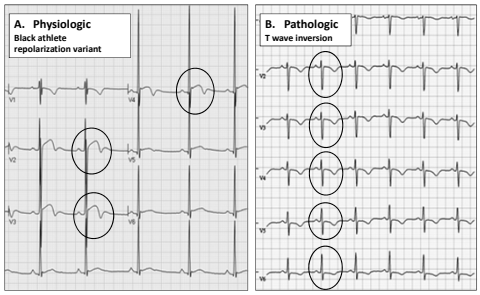
Normal or Abnormal?



Evaluation of Inferolateral TWI

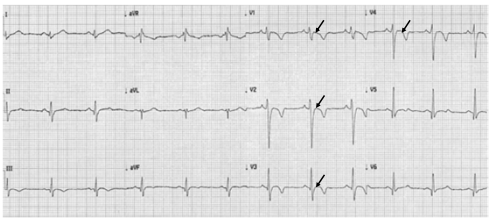
Additional testing to rule out cardiomyopathy

- 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



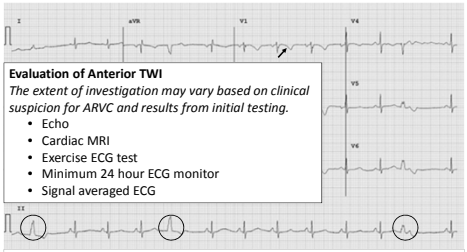
Physiologic (A) and pathologic T wave inversion (B). Panel A demonstrates physiologic repolarization in a black athlete with TWI in V1-V4 preceded by J-point and convex 'domed' ST segment elevation (green circles). **Panel B demonstrates pathologic TWI in V1-V6 with absent J-point elevation and a downsloping 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

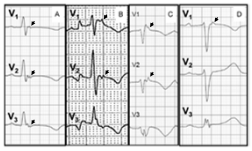
Definition

2010 ARVC/D Task Force Criteria:

"Reproducible low amplitude signal between end of QRS complex to onset of the T wave in the right precordial leads (V1 toV3)."

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."



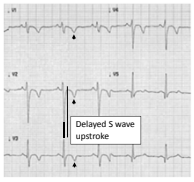
Platonov et al. *Heart Rhythm*, 2016

Epsilon Wave

Epsilon waves are typically a manifestation of more advanced disease and unlikely to be an isolated ECG finding

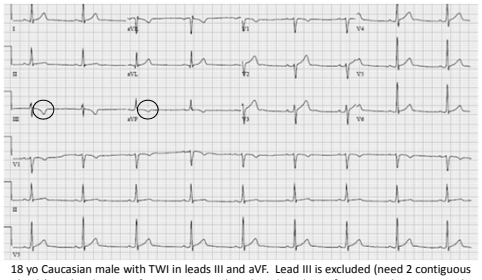
In patients with ARVC that express an epsilon wave:

- 89% 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 evaluation for other ECG abnormalities suggestive of ARVC (TWI; delayed S wave upstroke; low limb lead voltage).



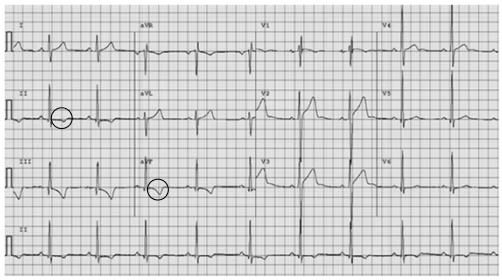
Inferior T Wave Inversion

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.

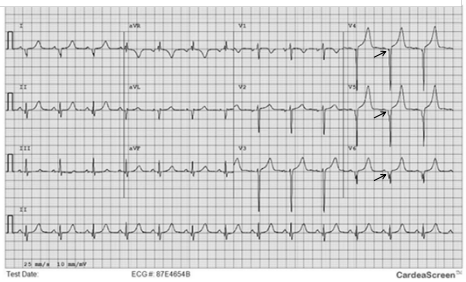
Inferior T Wave Inversion



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

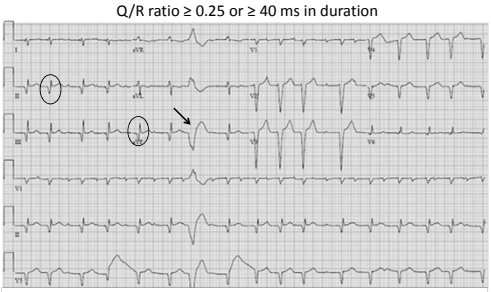
Pathologic Q Waves

New Criteria: Q/R ratio ≥ 0.25 or ≥ 40 ms in duration



Pathologic Q Waves

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.

Table 2 Evaluation of ECG abnormalities in athletes

ECG abnormality	Potential cardiac disease*	Recommended evaluation†	Considerations
T wave inversion in the lateral or inferolateral leads	HCM DCM LVNC ARVC (with predominant left ventricular involvement) Myocarditis	Echocardiogram Cardiac MRI Exercise ECG test Minimum 24 hours ECG monitor	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.
T wave inversion isolated to the inferior leads	HCM DCM LVNC Myocarditis	Echocardiogram	Consider cardiac MRI based on echocardiogram findings or clinical suspicion.
T wave inversion in the anterior leads‡	ARVC DCM	Echocardiogram Cardiac MRI Exercise ECG test Minimum 24 hours ECG monitor Signal averaged ECG	The extent of investigations may vary based on clinical suspicion for ARVC and results from initial testing.
ST segment depression	HCM DCM LVNC ARVC Myocarditis	Echocardiogram	Consider cardiac MRI and additional testing based on echocardiogram findings or clinical suspicion.
Pathological Q waves	HCM DCM LVNC Myocarditis Prior myocardial infarction	Echocardiogram Coronary artery disease risk factor assessment Repeat ECG for septal (V1-V2) QS pattern; above investigations recommended if septal Q waves are persistent	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.
Complete left bundle branch block	DCM HCM LVNC Sarcoidosis Myocarditis	Echocardiogram Cardiac MRI (with stress perfusion study)§	A comprehensive cardiac evaluation to rule out myocardial disease should be considered.

Evaluation of Pathologic Q Waves

Echocardiogram

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

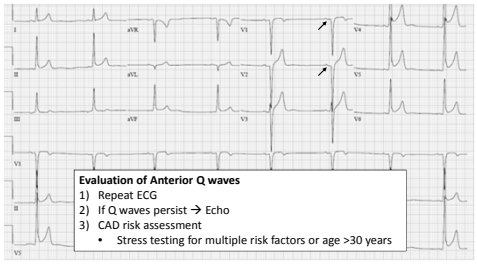
Coronary artery disease risk factor assessment

- 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 (V1-V2) QS pattern

- "pseudo-septal" infarct pattern from high lead misplacement

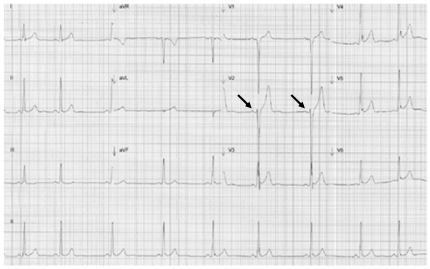
Anterior Q Waves V1-V2 / QS Pattern



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

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

Anterior Q Waves?



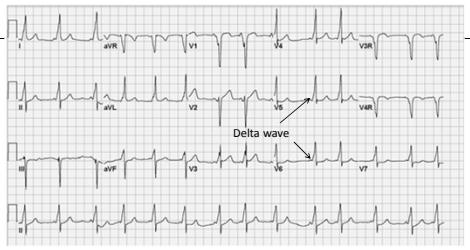
Repeat ECG in same athlete shows RS in V2 (arrows). This suggests QS pattern was lead placement issue. No further evaluation needed.

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.

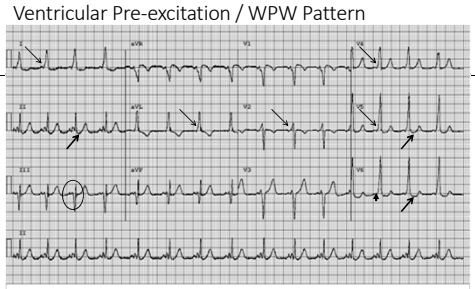
ECG abnormality	Definition
T wave inversion	≥1 mm in depth in two or more contiguous leads; excludes leads aVR, III and V1
► Anterior	► V2-V4 – excludes: black athletes with J-point elevation and convex ST segment elevation followed by TWI in V2-V4; athletes < age 16 with TWI in V1-V2; and biphasic T waves in only V3
► Lateral	► I and AVL, V5 and/or V6 (only one lead of TWI required in V5 or V6)
► Inferolateral	► II and aVF, V5-V6, I and AVL
► Inferior	► II and aVF
ST segment depression	≥0.5 mm in depth in two or more contiguous leads
Pathological Q waves	Q/R ratio ≥0.25 or ≥40 ms in duration in two or more leads (excluding III and aVR)
Complete left bundle branch block	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
Profound non-specific intraventricular conduction delay	Any QRS duration ≥140 ms
Epsilon wave	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
Ventricular pre-excitation	PR interval <120 ms with a delta wave (slurred upstroke in the QRS complex) and wide QRS (≥120 ms)
Prolonged QT interval*	QTc ≥470 ms (male) QTc ≥480 ms (female) QTc ≥500 ms (marked QT prolongation)
Brugada type 1 pattern	Coved pattern: initial ST elevation ≥2 mm (high take-off) with downsloping ST segment elevation followed by a negative symmetric T wave in ≥1 leads in V1-V3
Profound sinus bradycardia	<30 beats per minute or sinus pauses ≥3 s
Profound 1° atrioventricular block	≥400 ms
Mobitz type II 2° atrioventricular block	Intermittently non-conducted P waves with a fixed PR interval
3° atrioventricular block	Complete heart block
Atrial tachyarrhythmias	Supraventricular tachycardia, atrial fibrillation, atrial flutter
Premature ventricular contractions	≥2 premature ventricular contractions per 10 s tracing
Ventricular arrhythmias	Couplets, triplets and non-sustained ventricular tachycardia

Ventricular Pre-excitation / Wolff-Parkinson-White



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 / WPW Pattern



17 yo 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).

Table 2 Evaluation of ECG abnormalities in athletes

ECG abnormality	Potential cardiac disease*	Recommended evaluation†	Considerations
Multiple premature ventricular contractions	HCM DCM LVNC ARVC Myocarditis Sarcoidosis	Echocardiogram 24 hours ECG monitor Exercise ECG test	If >2000 PVCs or non-sustained ventricular tachycardia are present on initial testing, comprehensive cardiac testing inclusive of cardiac MRI is warranted to investigate for myocardial disease. Consider signal averaged ECG.
Ventricular pre-excitation	Wolff-Parkinson-White	Exercise ECG test Echocardiogram	Abrupt cessation of the delta wave (pre-excitation) on exercise ECG denotes a low-risk pathway Electrophysiological study for risk assessment should be considered if a low-risk accessory pathway cannot be confirmed by non-invasive testing. Consider electrophysiology study for moderate to high intensity sports.
Prolonged QTc	Long QT syndrome	Repeat resting ECG on separate day Review for QT prolonging medication Acquire ECG of first-degree relatives if possible	Consider exercise ECG test, laboratory (electrolyte) screening, family screening and genetic testing when clinical suspicion is high. Consider direct referral to a heart rhythm specialist or sports cardiologist for a QTc ≥500 ms.
Brugada type 1 pattern	Brugada syndrome	Referral to cardiologist or heart rhythm specialist	Consider high precordial lead ECG with leads V1 and V2 in second intercostal space or sodium channel blockade if Brugada pattern is indeterminate. Consider genetic testing and family screening.
Profound sinus bradycardia <30 beats per minute	Myocardial or electrical disease	Repeat ECG after mild aerobic activity	Consider additional testing based on clinical suspicion.

Evaluation of Ventricular Pre-excitation

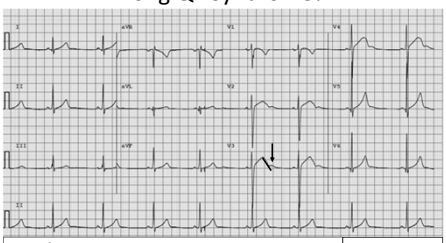
Exercise ECG test

- 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

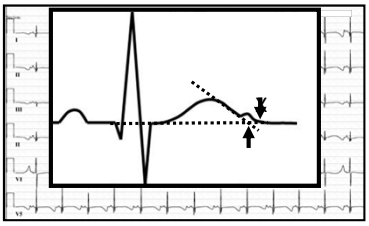
Echocardiogram

- Association of pre-excitation with Ebstein's anomaly and cardiomyopathy

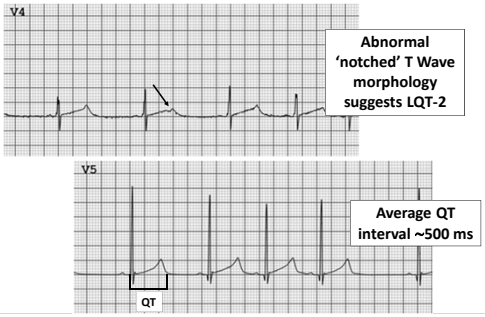
Long QT Syndrome?

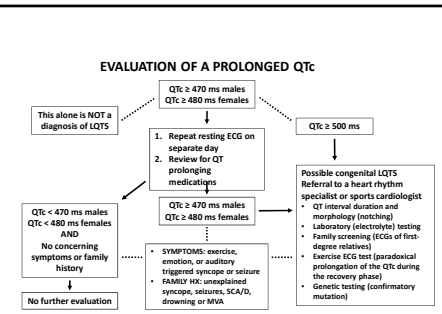


Normal ECG • QTc is normal • Don't include the U wave in anterior precordial leads! • "Teach-the-tangent" or "Avoid-the-tail" method for manual measurement of the QT interval	*No further evaluation needed*



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.





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:
siebert@uw.edu