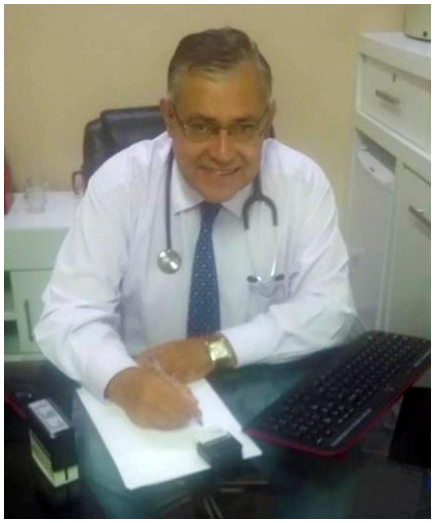
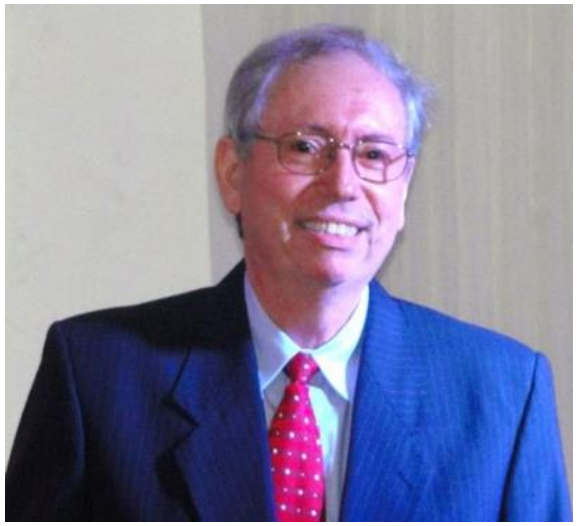
# Peculiar repolarization in African descendant elite athlete


https://ekgvcg.wordpress.com/

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# Case report

We report the case of an asymptomatic professional basketball player, 24 year-old African -Caribbean male, with curious early repolarization pattern in the anterolateral wall (V1-V6, I and aVL). The ECG was performed during periodic evaluation. Detailed examination was normal.

The ECG performed one year before was similar.

Personal antecedents were irrelevant. Deny use of drugs licit or illicit.

Negative familial background for sudden death or syncope in young first degree relatives.

Physical: Weight: 86 kg; Height: 2.02 m; Biotype: Asthenic; BP: 120/70 mmHg; HR: 51 bpm; normal height of the waveforms of jugular venous pulse (< 4 cm) with the patient reclined at a 45° angle; absence of cardiac manifestation of genetic disorder, such as Marfan's syndrome or facial signs associated with cardiac conditions. Normal peripheral pulses. Normal apex beat. Absence of thrill. Normal heart sound with physiological splitting of the second heart sound. A third heart sound was heard after the second heart sound, interpreted as rapid, high-volume filling of the left ventricle. Absence of murmurs.

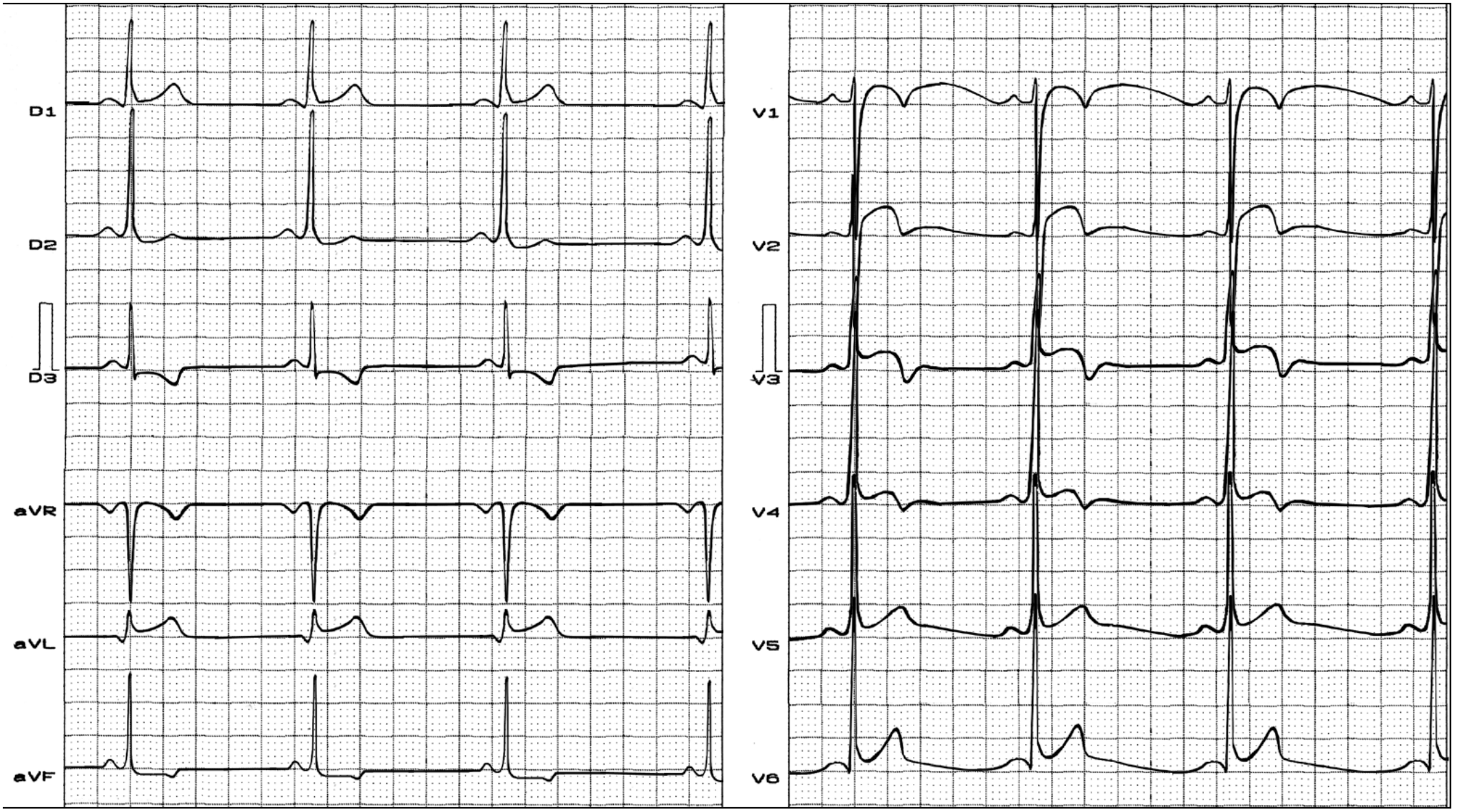
Normal vesicular breath sounds over the most of the both lung surface without adventitious sounds (crackles). They have an inspiration/expiratory ratio of 3 to 1 (normal).

Normal chest X-rays and echocardiogram.

Questions:

1) Which is the ECG diagnosis? 2) Is it necessary other complementary study?

**Name:** BCW; **Age:** 24yo.; **Sex:** Male; **Race:** Afro-Caribbean; **Weight:** 86 kg; **Height:** 2.02 m**; Biotype:** Asthenic; **Profession:** professional basketball player.




**Clinical diagnosis:** healthy patient. Tracing obtained in a periodical evaluation.

**ECG diagnosis:**

Dear Andrés, Raimundo, and Luis Carlos,

The abnormal repolarization in this patient can be found in athletes and has been described as part of the "normal athlete heart".

Although his physical exam and echocardiogram were normal, these individuals require close follow-up, since some of them eventually manifest phenotypical manifestations of heart disease like hypertrophic cardiomyopathy, ARVD, or other types of cardiomyopathy.

Thank you,

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PennState Health
Milton S. Hershey
Medical Center

Thank you for all these interesting case
In this particular case before I commit my self to the final diagnosis
It appears that the PR is short ( assuming paper speed is 25mm /s and email shows real size) beside ST/ T wave abnormality it also looks short
Next step how about an exercise test and echocardiogram ?
My ECG diagnosis
Early repolarization in an African American Athlete .
One has to rule out hypertrophic cardiomyopathy
The big question is sheathe he should allowed to play or not?
Thanks
Regards

Mohammad **Shenasa,** MD, FACC Heart & Rhythm Medical Group
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Dr. Mohammad Shenasa graduated from University of Tehran Faculty of Medicine. Spend two years at the University of Pennsylvania. Completed four years of Medicine and cardiology at Guy's Hospital University of London in United Kingdom. Completed a fellowship in cardiology and cardiac electrophysiology at Mount Sinai Medical Center, University of Wisconsin, Milwaukee campus. Dr. Shenasa held position as assistant professor of medicine at University of Wisconsin Milwaukee campus. Followed by associate professor of medicine at University of Montreal and research associate at McGill University, Montreal. He held a position as professor of medicine and surgery, director of cardiac electrophysiology and arrhythmia services at the University of Pittsburg, Pennsylvania. Dr. Shenasa also had a sabbatical as a visiting professor at the University of Munster in Germany. He is a fellow of American College of Cardiology, American Heart Association, European Society of Cardiology, and Heart Rhythm Society. He is the author of four cardiology text books and public extensive papers in the filed of cardiac arrhythmias and lectured nationally and internationally.

Dear friends, Professor Andrés Ricardo, Raimundo and Luiz Carlos,
This electrocardiogram breaks electrocardiology paradigms. First, in a young, asthenic, longitype sportsman, we would expect the ECG to show a vertical heart with R/S in I, r/S in aVL and negative T waves in aVL and TIII>TI. However, we see an emphasized gradient between R in I, II in regard to aVL. Inverted T wave in III, with depressed T wave, that would be remodeling of ST segment elevation and positive wave in aVL. The problem is that in a high takeoff, this is an epicardial phenomenon by excellence, there is no reciprocal remodeling. For it to exist, there has to be subendocardial pathology.
The deepest S waves are in aVR, that along with higher R in II and deeper S in V1 than in V2, and higher R in V4, V5 and V6 arise the suspicion of inferior septum, apex and inferior lateral wall hypertrophy.
In the precordial leads, ST elevation is observed in all leads, as it would be expected in a young black man, but ST should be shorter and vertical, because of the androgenic effect happening at that age, but it is vertical and with positive T waves in V2, V3, V4.
What can we conclude? That from an optimistic point of view we could say this young athlete has a physiological hypertrophy in the lateral wall of the apical and inferior septal region because of inhomogeneous distribution of endocardial tension receptors, depending on fetal genes reactive to intense strain and negative T waves that are patterns of juvenile waves. But being more critical, we should rule out a pathological ECG by any means possible, from vectorcardiogram to stress test, echo and cardiac magnetic resonance imaging to get the greatest certainty that this young man does not have cardiac problems and that he may continue playing, to seize what in the gene lottery favored him.

Warm regards, and fantastic case. Normal or pathological? This is the question.

Samuel **Sclarovsky** MD Israel

**Spanish**

**Queridos amigos Profesor Andrés Ricardo, Raimundo y Luiz Calos**
**Este electrocardiograma rompe los esquemas de la electro cardiología. Primero en un joven deportista, asténico, longilineo esperaríamos que el ECG muestre un corazón vertical con R/S en I, r/S en aVL y ondas T negativas en aVL y T III > TI. No obstante observamos un gradiente acentuado entre R en I, II respecto aVL. La onda T invertida en III, con onda T deprimida , que seria remodelación de la elevación del segmento ST y onda positiva en aVL. El problema es que en high take off, que es un fenómeno epicárdico por excelencia, no hay remodelación reciproca. Para que esta exista tiene que haver patología subendocárdica**
**Las S mas profundas están en aVR , Que junto con las R mas altas en II y las S mas profundas en V1 que en V2 y las R mas altas en V4,V5 y V6 son sospechosa de hipertrofia del septo inferior, ápex y pared lateral inferior.**
**En las derivaciones precordiales se observa elevación del ST en todas las derivaciones, como seria de esperar en joven de raza negra, pero es de esperar que el ST sea muy corto y vertical, debido al efecto androgénico que ocurre a esta edad .pero es vertical y con ondas T positiva en V2 ,V3 ,V4**
**Que se podría concluir?. Que desde el punto de vista optimista decir que este joven atleta tiene una hipertrofia fisiológica en la pared lateral de la región apical e septal inferior debido a la distribución no homogénea de los receptores de tensión endocardios, dependiente de lo genes fetales reactivos al esfuerzo intenso y que las ondas T negativas son patrones de ondas juveniles Pero siendo mas critico, debería descartar un electro patológico con todos los medios posibles desde el vectocardiograma, la prueba de esfuerzo, el ecocardiograma y la resonancia magnética cardiaca para dar la mayor seguridad que este joven no tiene problemas cardiacos y que puede seguir jugando , para aprovechar lo que en la lotería de los genes les tocaron favorables**
**Un fraternal abrazo .Fantástico caso.**
**normal o patológico? This is the question**
**Samuel Sclarovsky**

Hello. This is the ECG pattern seen in black athletes, which is considered as a normal variant. No further evaluation is necessary in asymptomatic individuals (**Drezner JA, et al. Br J Sports Med 2013;47:125–136**).

Best regards

Kjell Nikus MD PhD

Tampere

Finland

1. Considering Drezner's studies and the Seattle criteria for the electrocardiographic evaluation of athletes, which consider normal alterations in this population in 45% of Caucasians and 60-90% of afro-descendants, the ECG does not present pathological criteria, having a pattern expected for his race and profession. We conclude that the ECG presents early repolarization pattern, a likely normal variant.
2. For a supplementary evaluation and to rule out overtraining, we would request ergometer test to evaluate the response to increase in sympathetic tone with normalization of ventricular repolarization, besides 24 h Holter to measure heart rate variability (HRV).

**Observation:** The following contributed to this reply: Dr. Alfredo José **da Fonseca**, and the residents from the Medical Clinic of the HC-FMUSP: Larissa **Barbosa Talharo**, Gabriel Afonso **Dutra Kreling** and Layara **Lipari**.

**Dr. José Grindler**
Diretor de Serviço: Eletrocardiologia HC. Faculdade de Medicina USP

Portuguese: 1) Considerando os estudos de Drezner e os critérios de Seattle para avaliação eletrocardiográfica de atletas, que considera alterações normais nessa população em 45% dos caucasianos e 60-90% de afrodescendentes, o ECG não apresenta critérios patológicos, tendo um padrão esperado para a raça e profissão. Concluímos que o ECG apresenta padrão de repolarização precoce, provável variante normal.2.) Para avaliação complementar e afastar "overtraining", solicitaríamos teste ergométrico afim de avaliar resposta ao aumento do tônus simpático com normalização da repolarização ventricular, além de um Holter de 24 horas para mensuração da variabilidade da frequência cardíaca (VFC).

**Contribuíram com a resposta**: Dr. Alfredo José **da Fonseca**, e os residentes de Clínica Médica do HC-FMUSP: Larissa **Barbosa Talharo**, Gabriel Afonso **Dutra Kreling** e Layara **Lipari.**

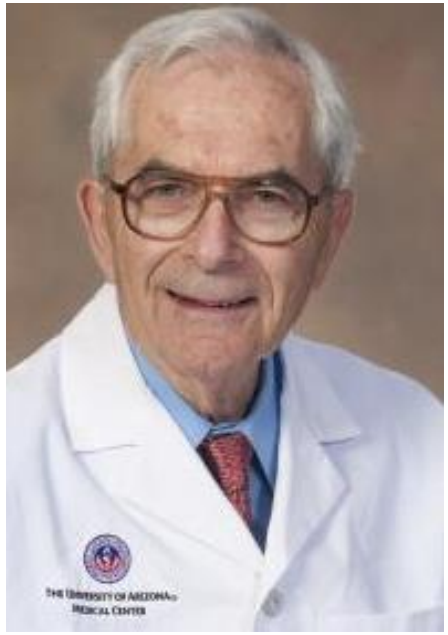
**Dr. José Grindler**

Diretor de Serviço: Eletrocardiologia HC
Faculdade de Medicina USP

It is interesting that athletes of African descent have a relatively high incidence of apparent abnormalities that suggest ARVC, such as the one in this presentation. It has been noted that these ECGs have ST segment elevation in the precordial leads and that is not observed in ARVC. Frank Ref Papadakis M et al Eur Ht J, 2011;32; 2304.

Frank Marcus
Professor Emeritus of Medicine at the University of Arizona, College of Medicine, in Tucson, Arizona.

From 2001 to 2008 Dr. Marcus was the principal investigator of an NIH-sponsored study “The Multi-Disciplinary Study of Arrhythmogenic Right Ventricular Cardiomyopathy/Dysplasia.” He is a principal investigator of an NIH-sponsored study, "Genetics, Mechanisms and Phenotypes of Arrhythmogenic Cardiomyopathies," that runs until 2018.



# Final comments

# Study methodology in detecting athlete candidates in risk

I. Preadmission and Periodical Evaluations: each 2 years.
II. Personal and Family Clinical History
III. Physical Examination: mandatory for any candidate**.**

# I) Significance of personal and familial clinical history

1) Ask questions about SD in first-degree relatives under 45 years old;
2) Ask questions about the knowledge in the family about HCM, LQTS, Marfan-type somatic habit, syndactyly, etc;
3) Personal history of murmur in childhood;
4) Personal history of dizziness, syncope, palpitations, intolerance to exercise, precordialgia, dyspnea, etc.
5) Dizziness or syncope during or after exercise, may indicate the presence of: HCM, dromotropic disorder, MVP, aortic stenosis or arrhythmia;
6) Precordialgia intra- or post-strain may indicate early coronary disease(CAD);
7) Excessive/progressive dyspnea may indicate valvular diseases, pulmonary disease, or structural heart disease;
8) Palpitations during or after exercise may be a sign of arrhythmia.
9) Ask questions about the current or past use of legal (tobacco, alcohol) and illegal drugs;
10) Recent history of virus infection may lead to symptoms compatible to myocarditis;
11) History of congenital heart disease(CHD)) or cardiac surgery;
12) Any background that may imply greater risk for CHD. E.g.: Maternal rubella, exposition to toxics used or environmental.

# II) Value of Pre-participation physical examination

1) Anthropometrical evaluation: weight, height, BP and percentage of body fat;

2) Identification and characterization (intensity, location and time of cycle) of murmurs and arrhythmias, standing and in supine position;

3) Recognize phenotypes: e.g. Marfan, Noonan and Holt-Oram syndrome, supravalvular aortic stenosis, Williams syndrome.

4) Measurement of BP in superior and inferior limbs, and assessment of femoral, radial and foot pulses to exclude Aorta coarctation.

5) Auscultation must be performed in decubitus and standing to identify murmurs influenced by dynamic obstruction in the LV outflow tract; detection of extracardiac clicks and sounds;

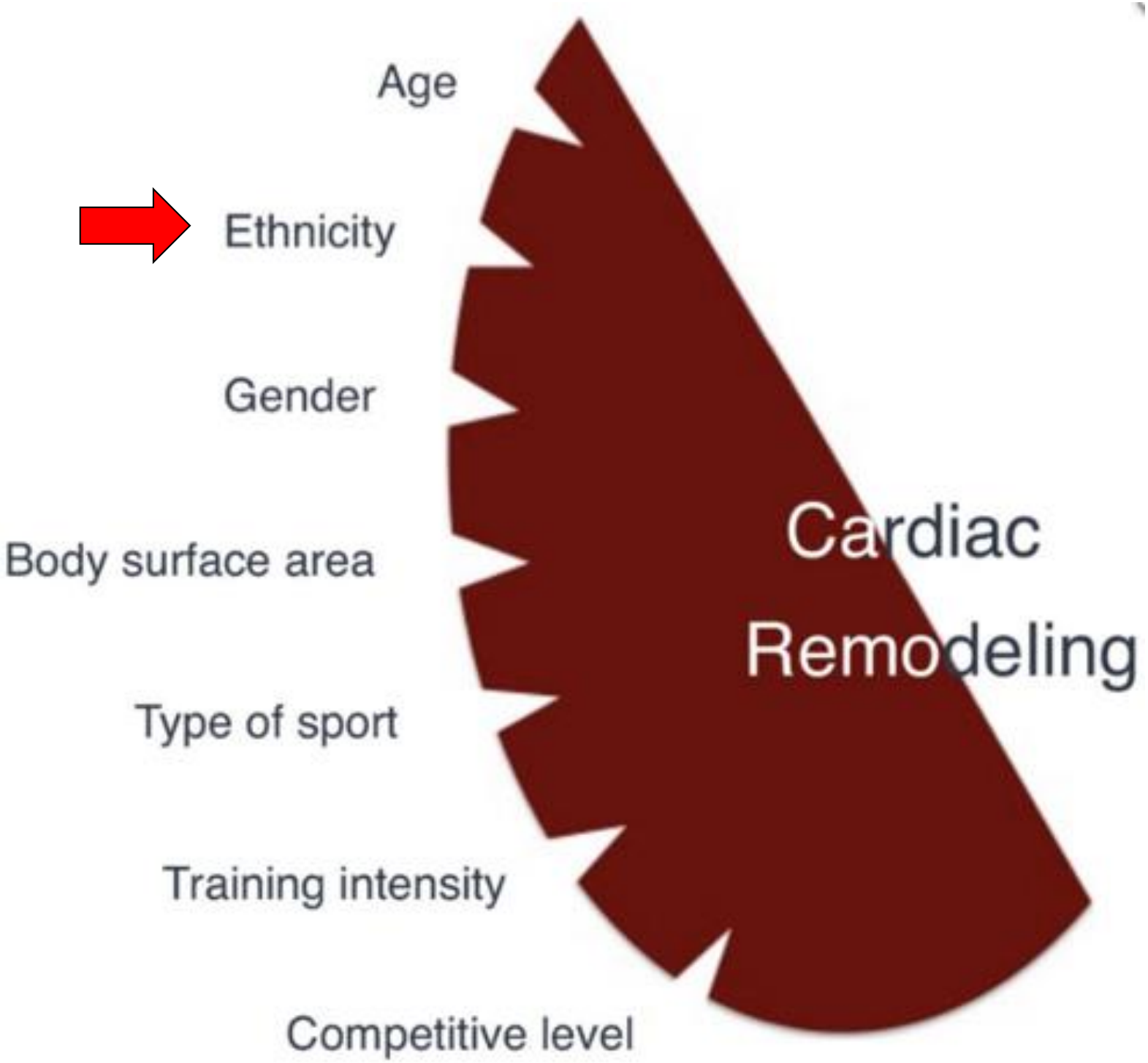
6) Muscular-skeletal aptitude. Try to detect medical conditions or skeletal muscles that may predispose to injuries or diseases during a competition.

# III) Non-invasive supplementary tests

## I) Electrocardiogram (Screening ECGs for young competitive athletes)

There are conflicting recommendations from the American Heart Association and the European Society of Cardiology regarding screening ECGs before participation in sports. The role of the ECG in preparticipation sports screening for adolescent athletes is a major area of controversy today. The use of an ECG as a screening strategy has been questioned, with a large number of abnormal test results observed in athletes resulting from the ECG changes that occur in a highly trained individual overlapping with findings suggestive of a pathologic condition. An abnormal 12-lead ECG triggers further examinations, which are expensive given the low diagnostic yield of most abnormal electrocardiographic patterns. A good screening test should be cost-effective and should influence a disease or health outcome that has a significant impact on public health. The reality is that the prevalence of SCD is low and no outcome-based data exist to determine whether early detection saves lives. Further, there is insufficient screening infrastructure, and the risk of screening and follow-up may be higher than that of the actual disease. Until outcomes data demonstrate a benefit with regard to SCD, universal screening cannot be recommended (**Asplund 2016**). The use of ECG screening has been repeatedly rejected in the United States because of the high rate of false-positive results and an abundance of evidence suggesting that it is a cost-ineffective tool for screening. The addition of an ECG enhances the ability to identify disease, and modern athlete-specific ECG interpretation standards used by experienced physicians provide low false-positive rates, improving the cost-effectiveness while preserving sensitivity. The evidence is clear that if athletes are screened, ECG-inclusive strategies are most likely to meet the primary aim of preparticipation cardiovascular screening. These advanced protocols have the potential to improve health and safety during sport events and should be considered the best practice in high-risk athletes when the sports cardiology infrastructure and oversight are readily available (**Asif 2016**). Refined criteria for ECG interpretation in athletes have been recently proposed to reduce the burden of false-positive screening (**Pascale 2016**). the new 2014 ‘Refined Criteria’ against the 2013 Seattle Criteria and the 2010 European Society of Cardiology (ESC) recommendations were evaluated in a cohort of Arabic, black and Caucasian athletes.

**Factors influencing associated with more pronounced cardiac remodeling**



Physiological RVH is commonly observed in both black and white athletes. The impact of ethnicity is minimal, which obviates the need for race-specific RV reference values (**Zaidi 2013**). However, in the context of frequent ECG repolarization anomalies in black athletes, the potential for erroneous diagnosis of ARVC is considerably greater in this ethnic group.

These differences can be explained by differences in:

I. Blood pressure modulation (**Ekelund 199**)

II. Endothelial function (**Kalinowski 2004**)

III. Arterial stiffness (**Nguyen 208**)

IV. Angiotensin-converting enzyme gene I/D polymorphisms **(Barley1996**)

V. Insulin-like growth factor-1 expression (**Pauliks 1999**).

The incidences of ECG abnormalities in Young elite Japanese athletes are statistically lower in the static exercise training group than in the endurance training group both in male and female (**Omiya 2016**).

# Common and uncommon ECG abnormalities in athletes (Corrado 2007)

| #Group 1 common ECG abnormalities | ##Group 2 uncommon ECG abnormalities |
|---|---|
| Sinus bradycardia: > 50% of cases (≥30 bpm) | Left atrial enlargement |
| Phasic Sinus Arrhythmia | Extreme QRS left axis deviation on FP LAFB type |
| AF in endurance sports practice | Right QRS axis deviation on frontal plane LPFB type |
| First-degree AV block. | Ventricular pre-excitation /Wolff–Parkinson–White type |
| Second-degree AV block type I or Wenckebach: 10% (in non athletes < 1 in 30,000 or 0.003%), and it disappears during exercise and atropine. | Complete RBBB and LBBBpattern |
| Notched QRS in ascending ramp of S wave in V1 or incomplete RBBB in 15% of athletes | Pathological Q wave ≥ 40ms |
| Benign Early Repolarization Pattern | Evil Early Repolarization Pattern "malignant" |
| Isolated voltage criteria for LVH. High voltage of left ventricle was observed 65.1% in man , and 27 and 26.7% in female (Omiya 2016). | Long or short QT intervals |
| Possible pattern of RVH/RVE: RV1+SV5 >10.5 | Inverted T waves ≥ 2 consecutives leads |
| Convex ('domed') ST segment elevation combined with T-wave inversion in leads V1--V4 in African-American / Afro-Caribbean athletes | ST segment elevation convex to the top in right precordial leads followed by negative T wave: it is possible in both Brugada syndrome and black athletes. In the first one, only V1-V2 or V3. In black athletes, V1-V4 with low J-point. |

#Group 1: Training-related no increase risk. ##Group 2: Training-unrelated, increased cardiovascular risk Required additional testing. <4 of cases.

In 2010, the European Society of Cardiology (ESC) produced 'revised' recommendations for the interpretation of ECGs of athletes (**Corrado 2010**). This was due to the increasing number of sporting governing bodies undertaking pre-participation cardiovascular screening reporting unacceptably high levels of false-positive ECGs arising from the overlap between physiological ECG patterns commonly observed in athletes and those suggestive of cardiac pathology. To demonstrate improved specificity, the authors reanalyzed the ECGs of 1005 highly trained athletes previously reported a decade earlier (**Pelliccia 2000**). Originally, 402 athletes (40%) presented an abnormal ECG (so-called 'group 2' changes), which was lowered to 11% using the 2010 ESC recommendations. Certain black ethnic populations, such as African, African-Caribbean and Black Latin-American, continue to demonstrate a high prevalence of abnormal ECGs (≈30%) when using the 2010 ESC recommendations (**Riding 2014; Papadakis2011; Magalski2011; Wilson2012**).

To address this issue, in 2012 an international team of experts produced the "Seattle Criteria" (**Drezner 2013**), a revision of ECG interpretation guidelines for athletes, aimed to provide greater accuracy in identifying those with cardiac pathology, while also attempting to reduce the false-positive rate. The Seattle Criteria have demonstrated favorable results over the ESC recommendations, with a reduction in the number of ECGs previously considered abnormal (17 to 4%) in a population of high-level athletes, while still identifying all athletes with cardiac pathology (**Brosnan2014**). Furthermore, the Seattle Criteria consider specific ethnic ECG facets such as anterior (V1–V4) T-wave inversion (commonly observed in up to 13% of black athletes) to represent an ethnically benign variant of the *athlete's* heart in those of black ethnicity, helping to reduce false-positive rates further.

Sheikh *et al* (**Shekh 2014**) published additional 'Refined Criteria' for ECG interpretation, based upon their experience of screening thousands of athletes using both the ESC recommendations and the Seattle Criteria. These authors demonstrated that the ECG patterns of isolated atrial enlargement (left and right), axis deviation (left and right) and (RVH) found in both the ESC recommendations and the Seattle Criteria provided an extremely low diagnostic yield for cardiac pathology. A unique feature of this investigation was a validation assessment in 103 young athletes with confirmed HCM whereby the Refined Criteria identified 98.1% of HCM cases (**Riding 2015**).

**ECG parameters used to define various ECG abnormalities in the European Society of Cardiology (ESC) recommendations, Seattle Criteria and Refined Criteria**

| ECG abnormality | ESC recommendations | Seattle Criteria | Refined Criteria |
|---|---|---|---|
| Left atrial enlargement (LAE) | Negative final portion of the P-wave in lead V1 ≥0.1 mV in depth and ≥40 ms in duration | P-wave duration of >120 ms in leads I or II with negative portion of the P-wave ≥0.1 mV in depth and ≥40 ms in duration in lead V1 | As ESC |
| Right atrial enlargement | P-wave amplitude ≥ 2 2.5 mm in leads II, III or aVF | As ESC | As ESC |
| Left QRS-axis deviation (LAD) | −30° to −90° | As ESC | As ESC |
| Right QRS-axis deviation (RAD) | >115° | >120° | As ESC |
| RVH | R-wave in V1 + S-wave in V5 or V6 ≥1.05 mV | R-wave in V1 + S-wave in V5>1.05 mV and right axis deviation >120° | As ESC |
| QTc interval | >440 ms (men) and >460 ms (women) | >470 ms (men) and >480 ms (women) | As Seattle |
| Complete LBBB | QRS ≥120 ms predominantly negative QRS complex in lead V1 (QS or rS), and upright monophasic R-wave in leads I and V6 | As ESC | As ESC |

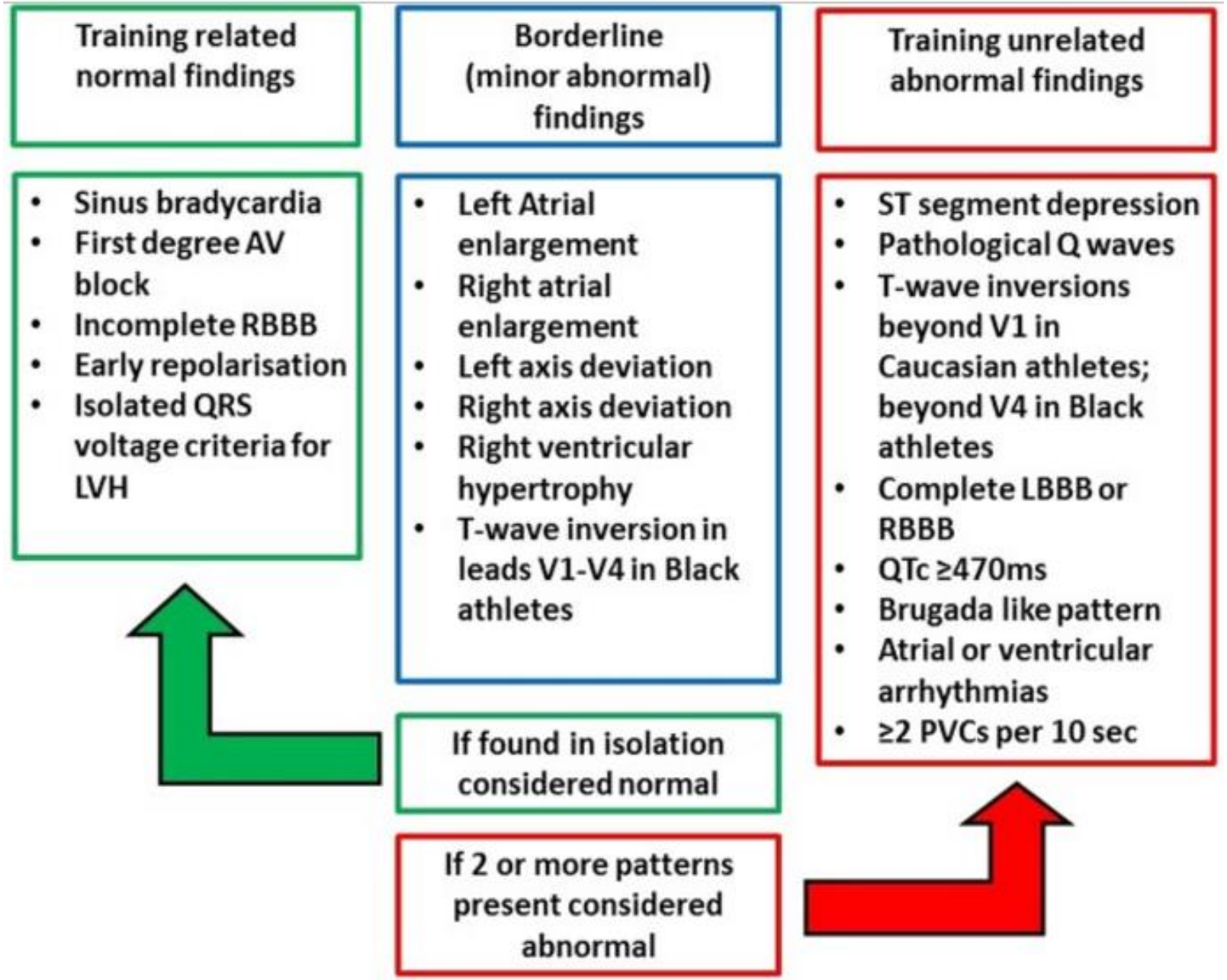
| ECG abnormality | ESC recommendations | Seattle Criteria | Refined Criteria |
|---|---|---|---|
| Complete RBBB | RSR pattern in anterior precordial leads with QRS duration ≥120 ms | Not relevant | As ESC |
| Intraventricular conduction delay | Any QRS duration >120 ms including RBBB and LBBB | Any QRS duration ≥140 ms or complete LBBB | As ESC |
| Pathological Q-wave | > 0.4 mV deep in any lead except III, aVR | >0.3 mV deep and/or >40 ms duration in ≥2 leads except III and aVR | ≥40 ms in duration or ≥25% of the height of the ensuing R-wave |
| Significant T-wave inversion | ≥2 mm in ≥2 adjacent leads (deep) or 'minor' in ≥2 leads | >1 mm in depth in ≥2 V2−6, II and aVF or I and aVL (excludes III, aVR and V1) | As Seattle |
| ST-segment depression | ≥0.5 mm deep in ≥2 leads | As ESC | As ESC |
| Ventricular pre-excitation | PR interval <120 ms with or without delta wave | PR interval <120 ms with delta wave | As Seattle |

**Refined Criteria:**

Differences between the ESC recommendations and the Seattle Criteria and the Refined Criteria is that athletes would not receive further cardiovascular evaluation when presenting with the following recognized training-related ECG changes in isolation; (1) LAE), (2) RAE), (3) LAD, (4) RAD and, (5) Sokolow–Lyon voltage criteria for RVH. In line with the Seattle Criteria, a corrected (Bazett's formula) QT interval (QTc) ≥470 ms in men and ≥480 ms in women, and T-wave inversion preceded by convex ST-segment elevation in leads V1–V4 in asymptomatic black athletes do not require further investigation. However, importantly, the

presence of two or more of the above ECG patterns would warrant secondary investigation. It is worth noting that the Refined Criteria are not an evolution of the 2012 Seattle Criteria, but use ECG parameters from both the 2010 ESC recommendations and the Seattle Criteria.

**Definition of an abnormal ECG using the Refined Criteria**



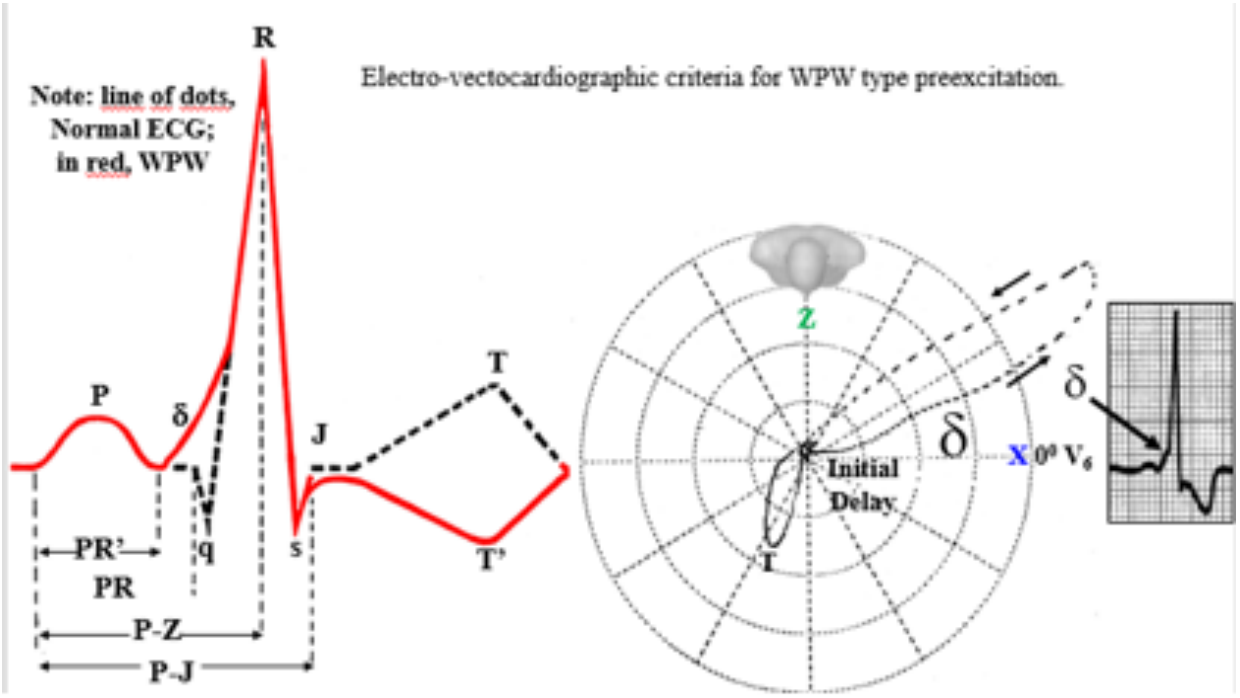
# ECG patterns in highly trained endurance athletes

## (Pelliccia 2000; Fagard 1997; Zehender 1990; Heidbuchel 2003)

**a.Distinctly abnormal ECG, suggesting cardiovascular disease:**

1. Left atrial enlargement: P-wave duration of ≥120 ms in leads I or II with negative final portion of the P-wave ≥0.1 mV in depth and ≥ 40 ms in duration in lead V1. Or P-terminal force (PTF-V1) exceeding 0.04 mm/s. This is the terminal, negative part of the P wave in lead V1 expressed as the multiplication of its depth in millimeters and width in seconds (mm/s). The normal PTF-V1 does not exceed 0.04 s wide and 1mm deep, i.e., 0.04 mm/s: Morris' index (**Morris 1964**);
2. Right atrial enlargement: P-wave amplitude ≥ 2.5 mm in leads II, III or aVF or P voltage ≥2.5 mm in at least one of inferior leads and or P wave of voltage ≥ at 1.5 mm in $V_2$ in association to R/S ratio >1
3. Striking increase in R or S wave voltage (>35mm) in any lead;
4. Extreme left axis deviation: between −30° to −90°
5. Right QRS-axis deviation (RAD) > +120°
6. Pathological Q-waves ≥ 4 mm in depth(except III, aVR) in ≥2 leads; ≥25% of the height of the ensuing R-wave
7. Inverted T wave ≥ 2mm in ≥ 2 leads;
8. Left bundle branch block
9. Non-specific intraventricular conduction delay or unspecified Intraventricular Conduction Delay/Disturbance (NICD). This applies to any pattern of intraventricular conduction disturbance that cannot be ascribed to block in the bundle branches or fascicles of left bundle of the specialized conduction system. In other words when a prolonged QRS duration ≥ 120ms exists, but does not satisfy the criteria for either left or right bundle branch block or pre-excitation pattern, the diagnosis of nonspecific (unspecified) intraventricular block or conduction delay is referred (**Bonner1978; Robles de Medina 1978**).
10. Complete RBBB(polemic): QRS duration ≥ 120 ms (or 0.12 s) in adults, greater than 100ms in children 4 to 16 years of age, and greater than 90ms in children less than 4 years of age.

10. Complete RBBB and LBBB are relatively rare in asymptomatic athletic populations, and current expert consensus guidelines recommend further clinical investigation upon detection of either ECG pattern. However, present data suggest that typical RBBB is not associated with structural cardiac pathology and may alternatively represent an ECG marker of exercise-induced right ventricular remodeling. In accordance with current guidelines, the presence of asymptomatic LBBB in athletes is not associated with normal exercise physiology and more likely indicative of underlying cardiac pathology. While long-term outcomes for asymptomatic athletes with RBBB or LBBB remain unknown, current evidence regarding these ECG patterns should be considered to improve the specificity of future athlete-specific ECG interpretation guidelines (**Kim 2015**).
11. Ventricular pre-excitation type Wolff–Parkinson–White pattern: Short PRi interval: <120 ms in adults and 90 ms in children; wider QRS complex: ≥100 ms 70% of the cases. 30% < 100 ms; thickening or notch at the onset of QRS complex: DELTA δ wave, duration 30 ms to 60 ms and voltage of up to 5 mm, which corresponds to early depolarization by ventricular mass, unaltered P-J interval (normal): 180 to 260 ms;, unaltered P-Z interval (normal): 230 ms (150 to 230 ms); alterations secondary to ventricular repolarization (ST-T): depending on aberrant depolarization and characteristic initial delay of QRS loop in the three VCG planes (Delta loop).



12. Short QTc interval: A universally accepted diagnostic cut off value of a short QT interval has not been defined (QTc interval ≤ 340–360 ms?) (**Giustetto 2011**). In congenital short ST syndrome, characteristically, the heart rate is not significantly modified with heart rate changes (**Kobza 2009**), and sometimes the T waves have great voltage, narrow base, which resemble T wave in "desert tent" of mild hyperkalemia. The entity is clinically characterized by a large set of signs and symptoms, such as syncope, sudden cardiac death and palpitations dizziness and high tendency to appearance of episodes of paroxysmal runs of atrial fibrillation. From the structural point of view, the heart is normal and electrophysiologically, there is significant shortening of refractory periods of atria and ventricles, being inducible (sustained VF) by programmed stimulation.

## Lower normal limit of the QT interval

| Author | QT interval | QTc interval |
|---|---|---|
| **Moss 1993, Luo S 1994** | 330 ms (children 310 ms) | 360-380 ms |
| **Vincent 1992** | | 360 ms (M) – 370 ms (F) |
| **Definition of "short QT"** | | |
| **Gussak 2000, Gaita 2003** | < 300 ms | < 300 ms |
| **Schimpf 2005** | < 320 ms | < 320 ms |

13. Long QTc interval: QTc values < 330 ms are considered short QT interval. Values of QTc > 450 ms are considered long QT intervals. Normal values of QTc are between 350 to 440 ms or 446 ± 15%. The normal maximal value that is accepted for the QT interval in males is 446 ms and in females 447 ms ± 15 >470 ms (men). If it exceeds 440 ms in males and 480 ms in females, the QT interval should be considered as prolonged. Values above 500 ms may cause a tendency to TdP.

14. Type 1 Brugada ECG pattern
15. Presence of epsilon waves: the presence of epsilon wave is a mayor criteria for ARVC the first cause of SCD among Young athletes.
16. QRSD of $V_1+V_2+V_3$ /$V_4$,$V_5$, $V_6$ or $\geq$ 1.2 (**Nasir 2004**).
17. Frequent premature ventricular contractions (>100º in 24h) (**McKenna 1994**).
18. Sustained or non sustained Monomorphic VT with LBBB morphology. If SAQRS of MVT with CLBBB morphology has inferior axis: it originates in RVOT. If SAQRS of MVT with CLBBB morphology has superior axis: it originates in the RVIT. Differential diagnosis with ARVC constitutes a frequent problem, especially in athletes showing ventricular arrhythmias with LBBB pattern (**Bauce 2010**). The revised ARVC diagnostic Task Force Criteria (TFC) incorporate cut-off values for RV EF and RV end-diastolic volume (EDV) on CMR (**Marcus 2010**). RV EF can help distinguish ARVC from physiological cardiac adaptation in athletes on CMR whereas RV EDV index cannot. A good alternative in athletes is the LV/RV EDV ratio, representing normal proportionate adaptation of both ventricles (**Luijkx 2012**).
19. Multiple morphologies of VT during the electrophysiological study.

**Observation:** Physiological cardiac adaptation to regular exercise, including biventricular dilation and T-wave inversion (TWI), may create diagnostic overlap with ARVC. TWI and balanced biventricular dilation are likely to represent benign manifestations of training in asymptomatic athletes without relevant family history. Diagnostic criteria for ARVC are nonspecific in such individuals. Comprehensive testing using widely available techniques can effectively differentiate borderline cases (**Zaidi 2015**).

**b. Mild abnormal ECG**

1. Increased R or S wave voltage (30 to 34mm) in any lead;
2. Q waves 2 to 3 mm in depth, in>2 leads;
3. T wave flat, minimally inverted or particularly tall (i.e.>15mm) in≥2 leads;
4. Abnormal R wave progression in the anterior precordial leads;
5. Left atria enlargement;
6. Short PR interval (<0.12‘)

# Electrocardiographic diferential diagnosis between athlete heart and ARVC/D

| | Athlete heart | ARVC/D |
|---|---|---|
| Epsilon wave | Major criteria task force | Possible, but exceptional in highly trained endurance athletes (1.57%) (**Macarie 2009**) |
| A prolonged S-wave upstroke in V1 through V3 | Absent | Very frequent (**Nasir 2004**) |
| Sustained or non sustained Monomorphic VT with LBBB morphology | Rare | Frequent and characteristic |
| Reduced QRS amplitude in > 6 leads | No | 65% of cases |
| Poor R wave progression on precordial leads | No | Very suggestive |
| Atrial arrhythmia | Possible, but rare | Frequent |
| Late potentials | Possible, but rare | It is a minor task force criteria |
| ST segment elevation | Characteristic convex upward of afro descendant | Polemic (**Papadakis 2011**)<br>Zhang 37% (**Zhang 2014; Peters 1999**) |

# Normal ECG training related normal finding (athlete's heart syndrome)

- Sinus bradycardia < 60 bpm
- Respiratory or Phasic sinus arrhythmia
- Prolonged PR interval duration (> 0.20‘ or 200ms) that disappear during exercise: first degree AV block;
- Second degree AV block Mobitz type 1 (Wenkebach)
- R or S voltage, 25 to 29mm;
- Isolated QRS voltage criteria for LVH: positive Sokolow-Lyon;
- Early repolarization pattern;
- The J-wave pattern on ECG is defined as a positive deflection at junction between the end of the QRS and the beginning of the ST-segment. This pattern has recently been associated with increased risk for idiopathic ventricular fibrillation, Brugada syndrome, and Short QT syndrome in the absence of cardiovascular disease. The interest for the clinical significance of J-wave pattern as a potential ECG hallmark of high risk for cardiac arrest has recently been reinforced by the growing practice of ECG screening, such as occurs in large population of young competitive athletes. Scientific evidence shows that the J-wave pattern is relatively common in trained athletes (ranging from 14% to 44%) and, differently from subjects who suffered from ventricular fibrillation, commonly localized in lateral leads while it is relatively rare to be found in inferior leads. Furthermore the J-wave pattern has been demonstrated to be a dynamic phenomenon related to the training status, with the larger prominence at the peak of training and with an inverse relation between magnitude of J-wave and heart rate. In addition the J-wave pattern is usually associated with other ECG changes, such as increased QRS voltages and ST-segment elevation, as well as LV remodeling, suggesting that it likely represents another expression of the physiologic athlete's heart. Finally the scientific data available demonstrated that during a medium follow-up period the J-wave pattern does not convey risk for adverse cardiac events, including SCD or VT/VF (**Pelliccia 2015**).
- Incomplete RBBB: RSR' pattern in V1 ,V2 (QRS duration < 0,12s or < 120ms);

- T-wave inversion in the anterior leads (V1–V4) in adult black athletes. Papadakis et al (**Papadakis 2011**) examining 904 black athletes and 1819 white athletes aged 14–35 years participating in 22 different sporting disciplines revealed that T-wave inversions were present in up to 25% of athletes and half of these individuals exhibit deep (−0.2 mV) T-wave inversions. T-wave inversions in leads V1–V4 were usually asymmetric or biphasic and frequently proceeded by convex ST-segment elevation. In black athletes, T-wave inversion was only preceded by ST-segment elevation or isoelectric ST-segments but never ST-segment depression. Detailed evaluation of these athletes with echocardiography, exercise stress tests, cardiac MRI and 24 h Holter failed to demonstrate any of the broad phenotypic features of HCM or ARVC, and following an almost 7-year follow-up episode there were no adverse events in black athletes with T-wave inversions in leads V1–V4. The same study also revealed that black controls of similar age had a T-wave inversion prevalence of 10% mainly distributed in the anterior leads indicating the T-wave inversion in leads V1–V4 in black athletes may represent ethnic variation which is exaggerated by exercise. Support for this hypothesis was evidenced by the fact that detraining among several athletes resulted in resolution of T-wave inversions within a few weeks.

**What is already known on this subject?** The high rate of false-positive ECGs in athletes is the main criticism of pre-participation screening with ECG. The 2013 Seattle Criteria improved the rate of false-positive findings from that of the 2010 ESC recommendations. It has been proposed that atrial enlargement, axis deviation and RVH should not be classified as an abnormal finding in athletes if found in isolation. Using this 'Refined' criterion, there is the potential to further reduce false-positive findings.

**What might this study add?**

The new 2014 Refined Criteria significantly improved specificity (94.0%) across all ethnicities compared with the 2012 Seattle Criteria and 2010 ESC recommendations (87.5% and 76.6%, respectively).

It is possible to reduce abnormal ECG prevalence rates to 3.6% and 2.1% in Arabic and Caucasian athletes. While significantly reduced, however, the prevalence of abnormal ECGs in black athletes continues to be 10% when using the 2014 Refined Criteria.

**How might this impact on clinical practice?**

This refined criteria supports the rationale that when found in isolation, axis deviation, atrial enlargement and RVH are normal physiological ECG patterns in asymptomatic athletes without a family history of SCD.

These ECG patterns ought to be incorporated into pre-existing ECG interpretational guidelines.

The 2014 Refined Criteria outperformed both the 2013 Seattle Criteria and the 2010 ESC recommendations by significantly reducing the number of false-positive ECGs in Arabic, black and Caucasian male athletes while remaining 100% sensitive in identifying all athletes with cardiac pathology associated with SCD. The 2014 Refined Criteria can not only be successfully applied to Afro-Americans, Black Canadians, Afro-Brazilian Afro-Caribbean, Afro-descendants or (Afro-diaspora) and Caucasian athletes, but also to Arabic athletes, helping to reduce both further investigation rates and the potential for unnecessary disqualifications, while maintaining sensitivity for conditions that may predispose athletes to SCD. Regular, intensive exercise results in physiological biventricular cardiac adaptation. Ethnicity is an established determinant of LV remodeling (the ethnic discrepancy); black athletes exhibit more profound LVH than white athletes (WAs). Right ventricular (RV) remodeling has not been characterized in black athletes, although the issue is pertinent because black athletes commonly exhibit ECG anomalies that resemble arrhythmogenic RV cardiomyopathy (ARVC).

# Early repolarization pattern new consensus definition (Macfarlane 2015)

The new definition of ERP requires the peak of an end-QRS notch and/or the onset of an end-QRS slur as a measure, denoted Jp, to be determined when an interpretation of early repolarization is being considered. One condition for early repolarization to be present is Jp ≥0.1 mV, while ST-segment elevation is not a required criterion.

In the figure of next slide we see the upper salmon line indicates the notch or slur amplitude, J peak (Jp), while the lower purple line indicates the baseline used as a reference with respect to which amplitudes should be measured. The blue lines indicate tangents to the initial component of the R-wave downslope. All of these waveforms are illustrations of the early repolarization pattern.

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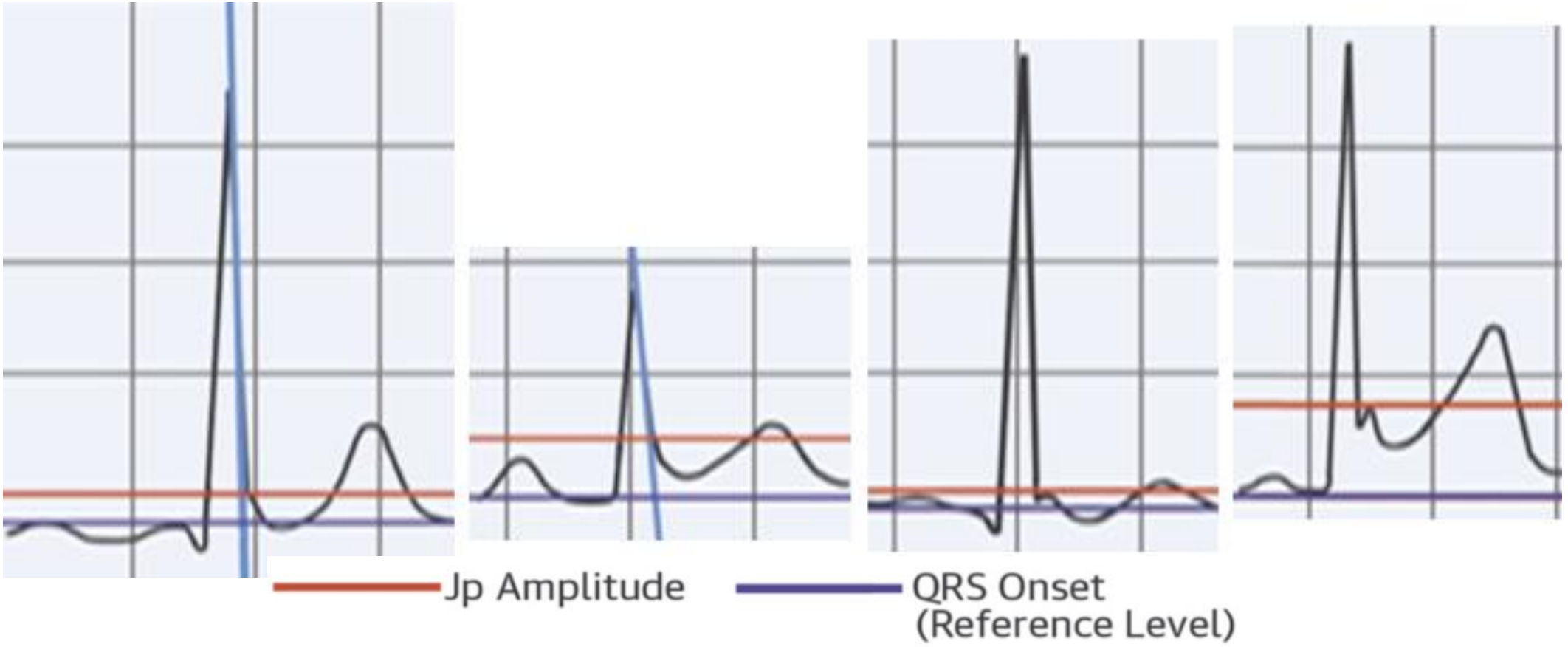
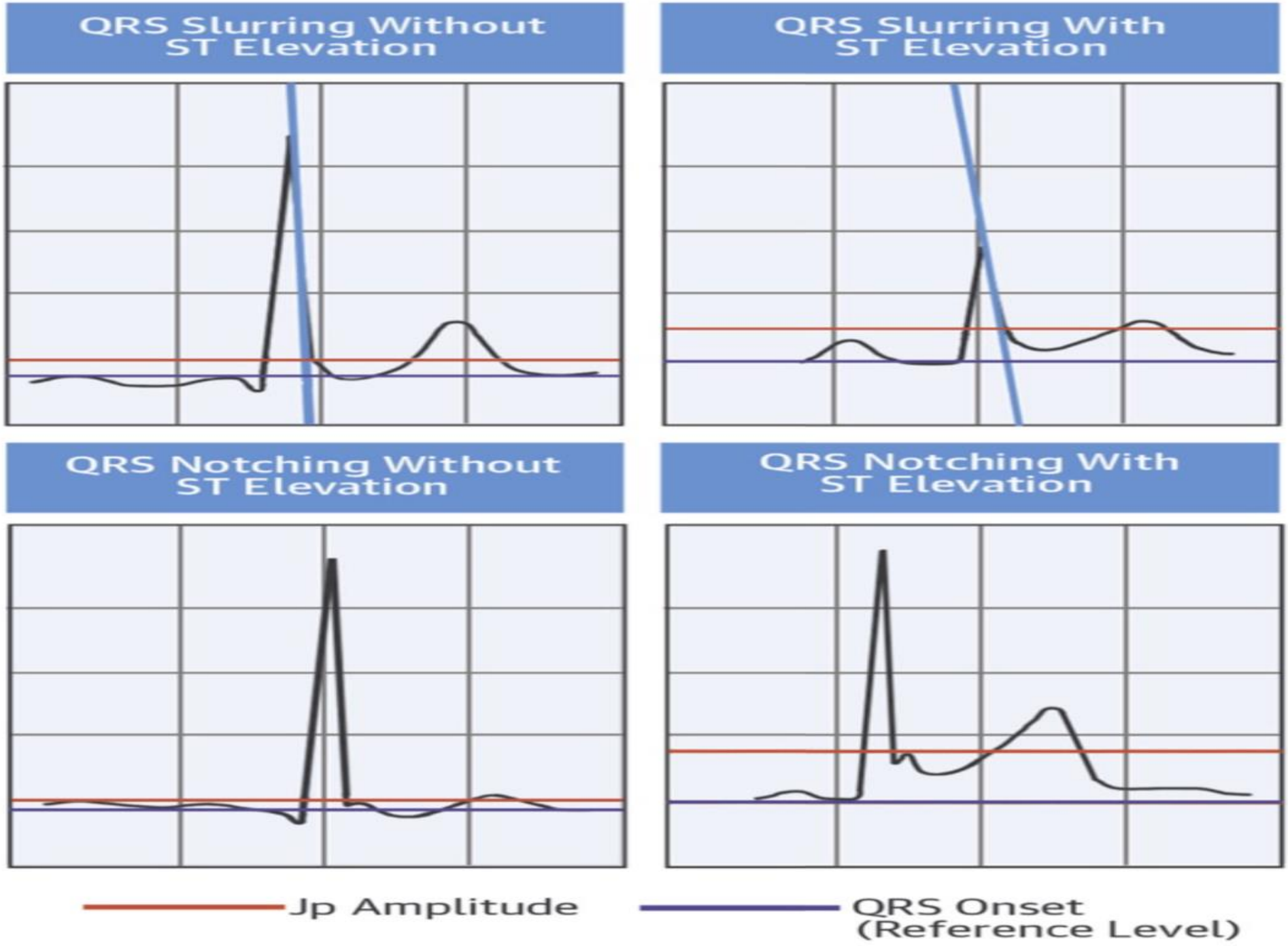
| QRS slurring without STSE | QRS slurring with STSE | QRS notching without STSE | QRS notching with STSE |
|---|---|---|---|

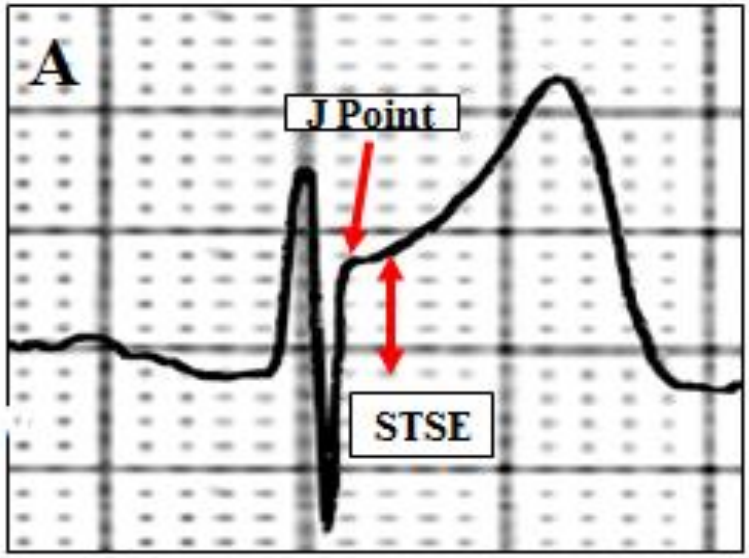



The upper salmon line indicates the notch or slur amplitude, J peak (Jp), while the lower purple line indicates the baseline used as a reference with respect to which amplitudes should be measured. The blue lines indicate tangents to the initial component of the R-wave downslope. All of these waveforms are illustrations of the early repolarization pattern (**Macfarlane 2015**).

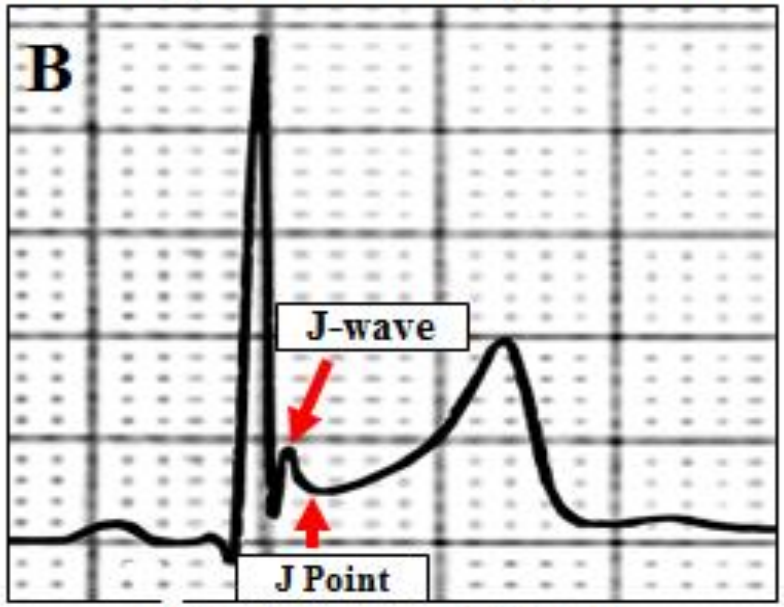



Macfarlane, P.W. et al. J Am Coll Cardiol. 2015; 66(4):470–7.

## A and B - Classical definition of early repolarization pattern: ST segment elevation

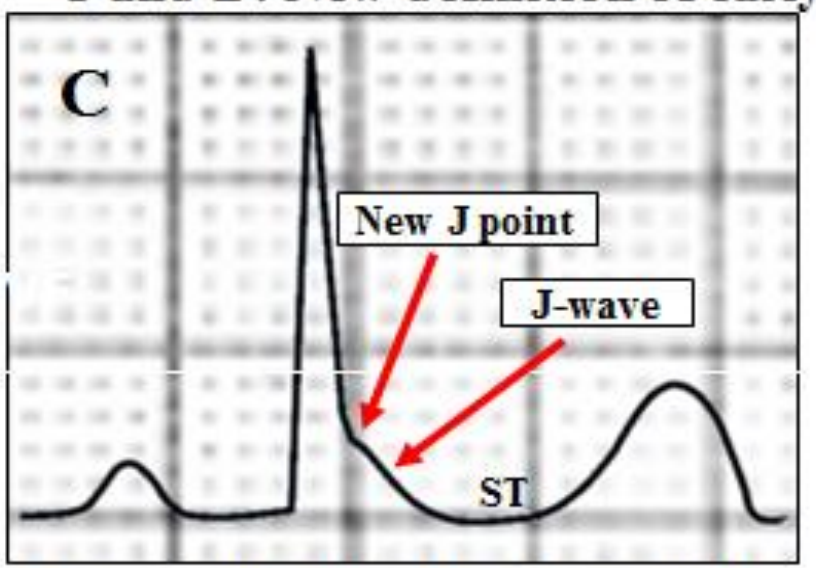



Without J-wave and STSE

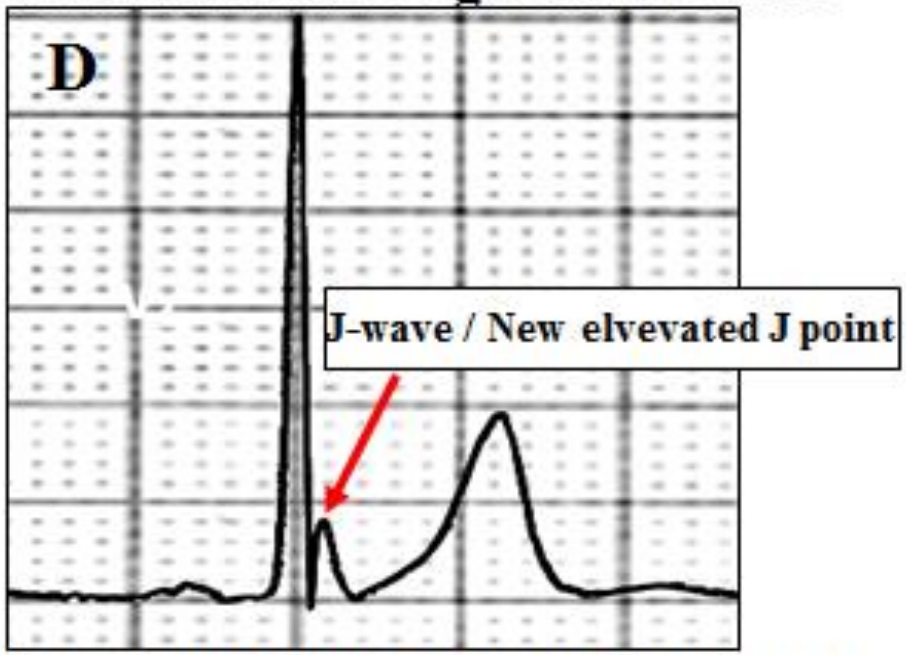



With J-wave and STSE

## C and D: New definition of early repolarization: without ST segment elevation



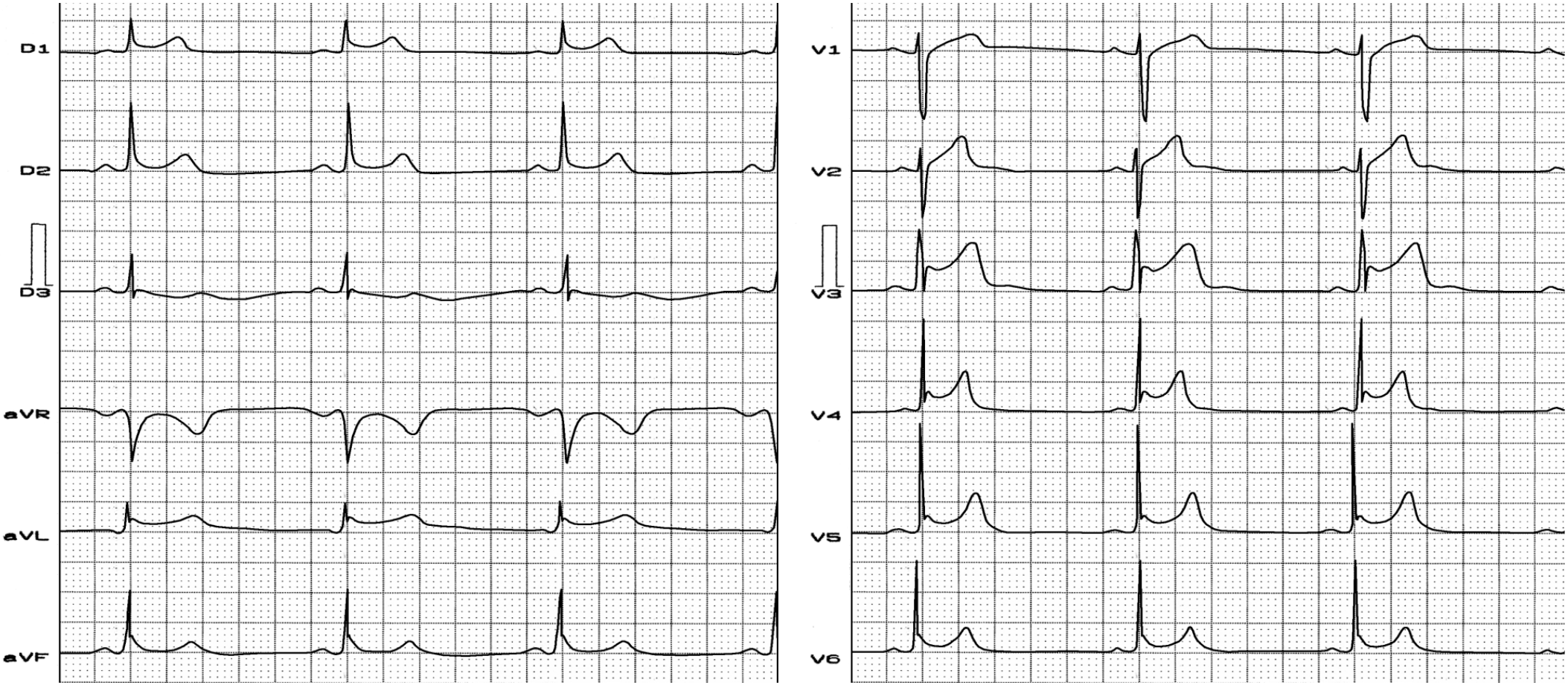

J-wave after P point without STSE



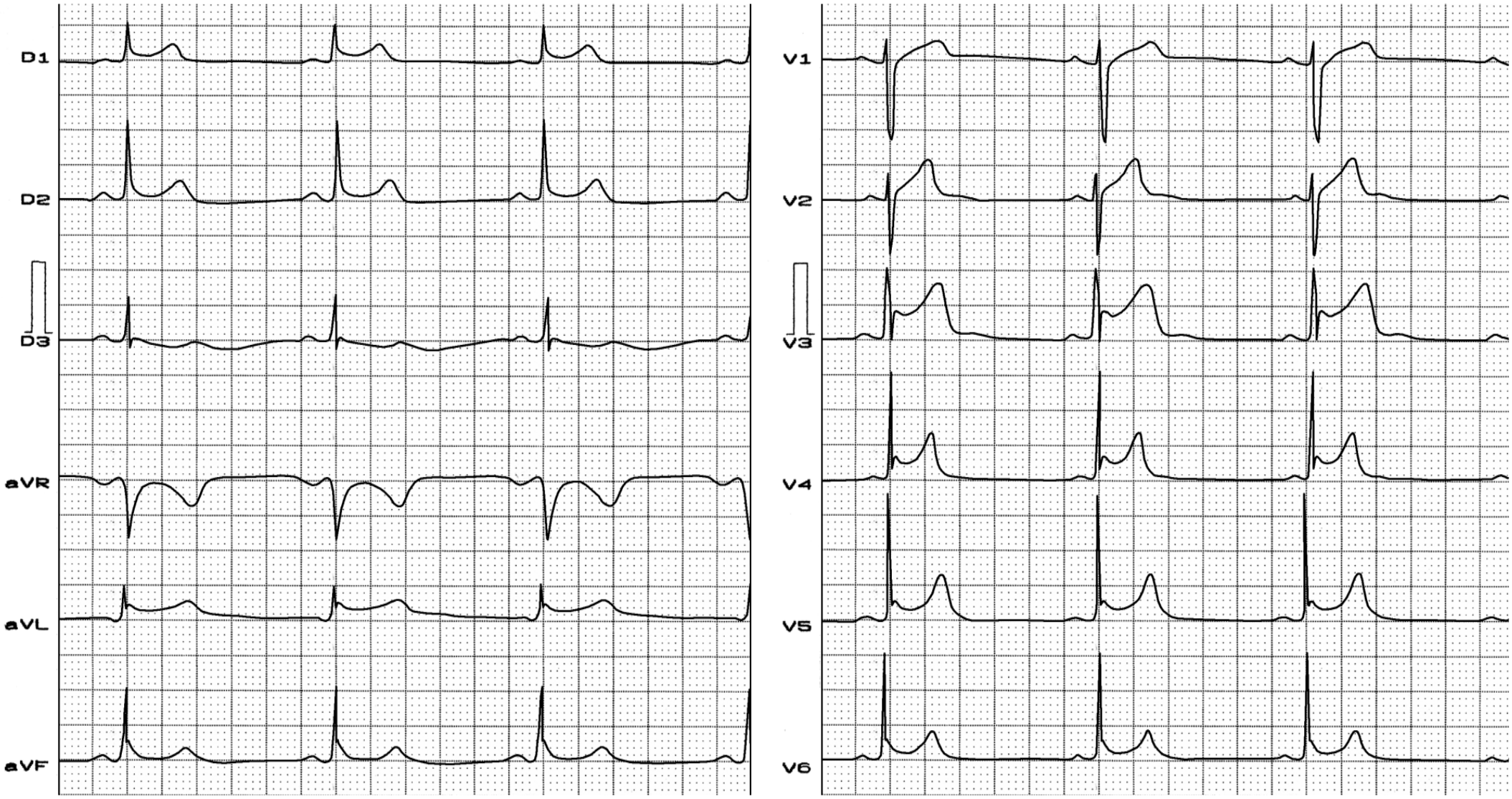

J-wave or new elevated J point without STSE

# Typical ECG of early repolarization syndrome in an athlete with bradycardia

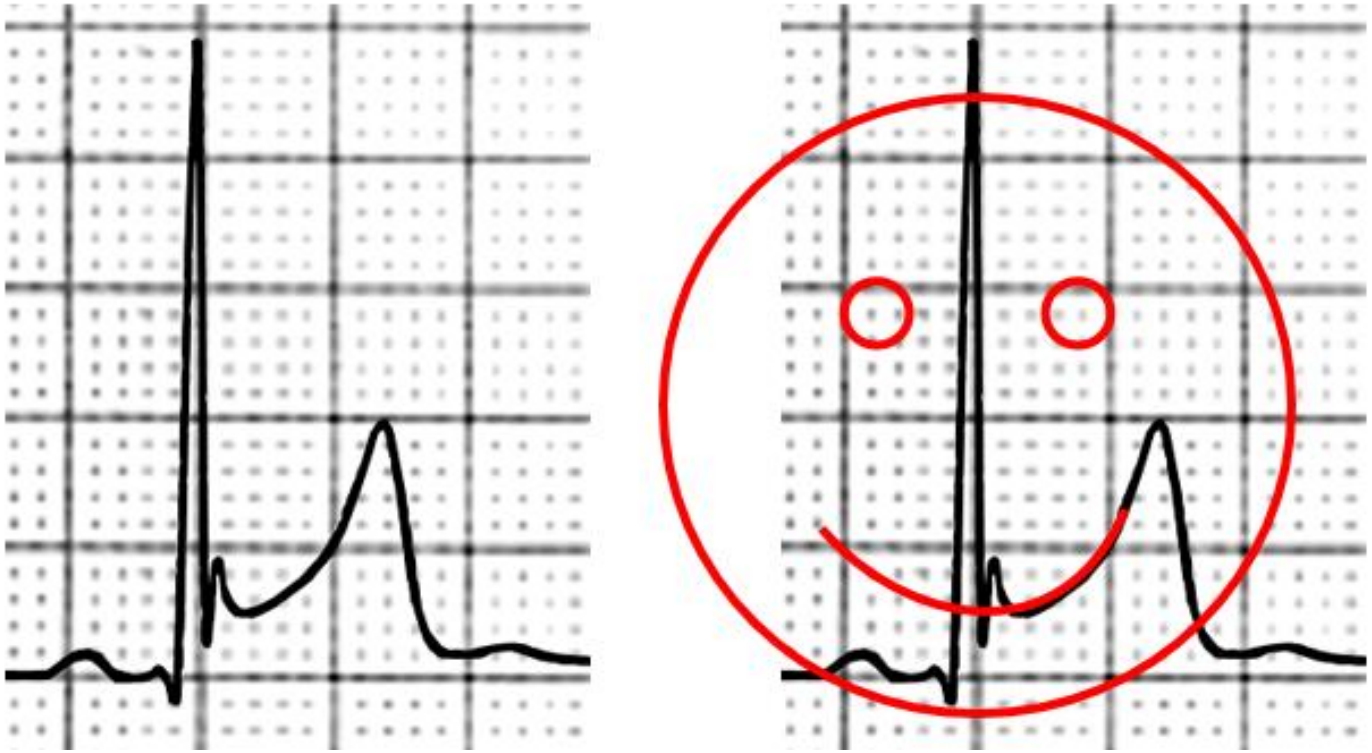
**Name:** DAS **Age:** 24y **Sex:** Male **Race:** Black **Weight:** 82 kg
**Height:** 1.91 m **Biotype:** Athletic **Profession:** professional basketball player



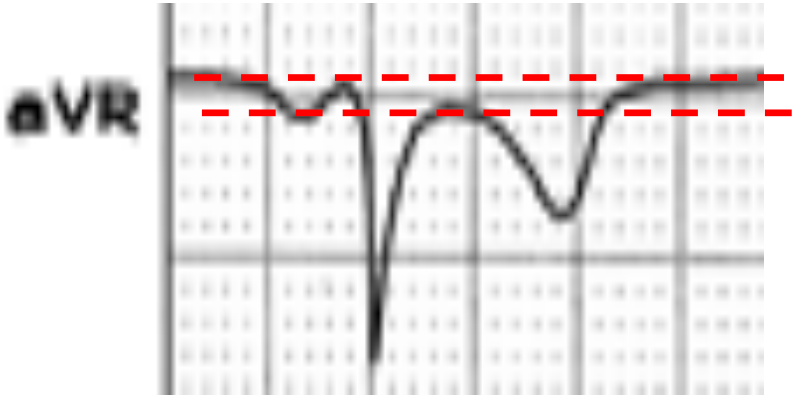

**ECG diagnosis:** sinus bradycardia, (HR 50 bpm). J point and ST segment with elevation > 4 mm in precordial leads from $V_3$-$v_5$ of superior concavity. Notch or slurring of terminal portion of the QRS complex (J point). ST segment elevation > 4mm in precordial leads $V_3$, $V_4$ and $V_5$.
**Conclusion:** sinus bradycardia, early repolarization syndrome.




**Electrocardiographic diagnosis:** typical ECG pattern of benign early repolarization: sinus bradycardia, P, QRS and T directed to the same place, ST segment elevation concave to the top from V2 to V5 followed by tall pseudo symmetrical T waves concordant with precedent polarity of QRS complexes. Absence of mirror image or reciprocal changes (with exception of aVR).



The figure shows V4 precordial lead with STSE concave to the top followed by large positive T wave that resembles a "smiling face".




Mirror image or reciprocal changes only in aVR lead

# ECG criteria that suggest benign Early Repolarization Pattern (ERP)

✓ HR: sinus bradycardia is frequent;

✓ Axes of QRS, ST segment and T wave, are oriented in the same direction in the FP;

✓ Deep and narrow Q waves followed by R wave of great voltage in left precordial leads;

✓ Notch or slurring of R wave descending branch;

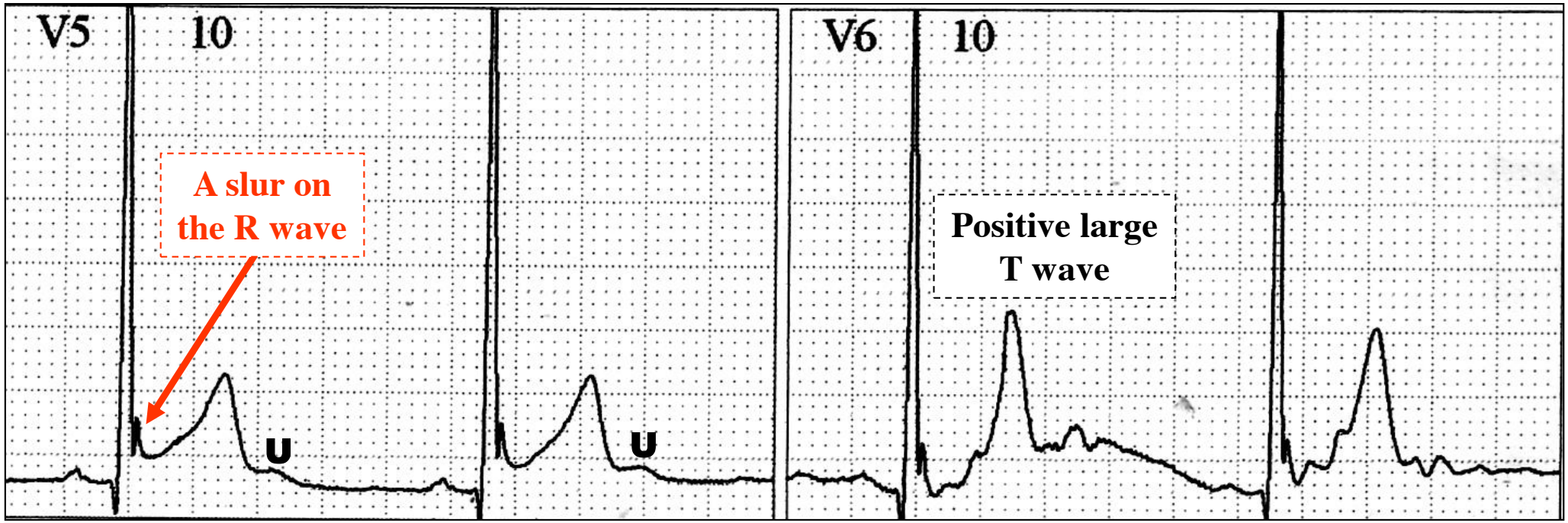
✓ Transition area in precordial leads of sudden occurrence;

✓ J point and ST segment elevation, usually < 2 mm (exceptionally it may be > 5 mm) of superior concavity in middle and/or left precordial leads and possibly in inferior leads;

✓ Possible reduction in J point and ST segment elevation by sympathetic action and sympathomimetic drugs;

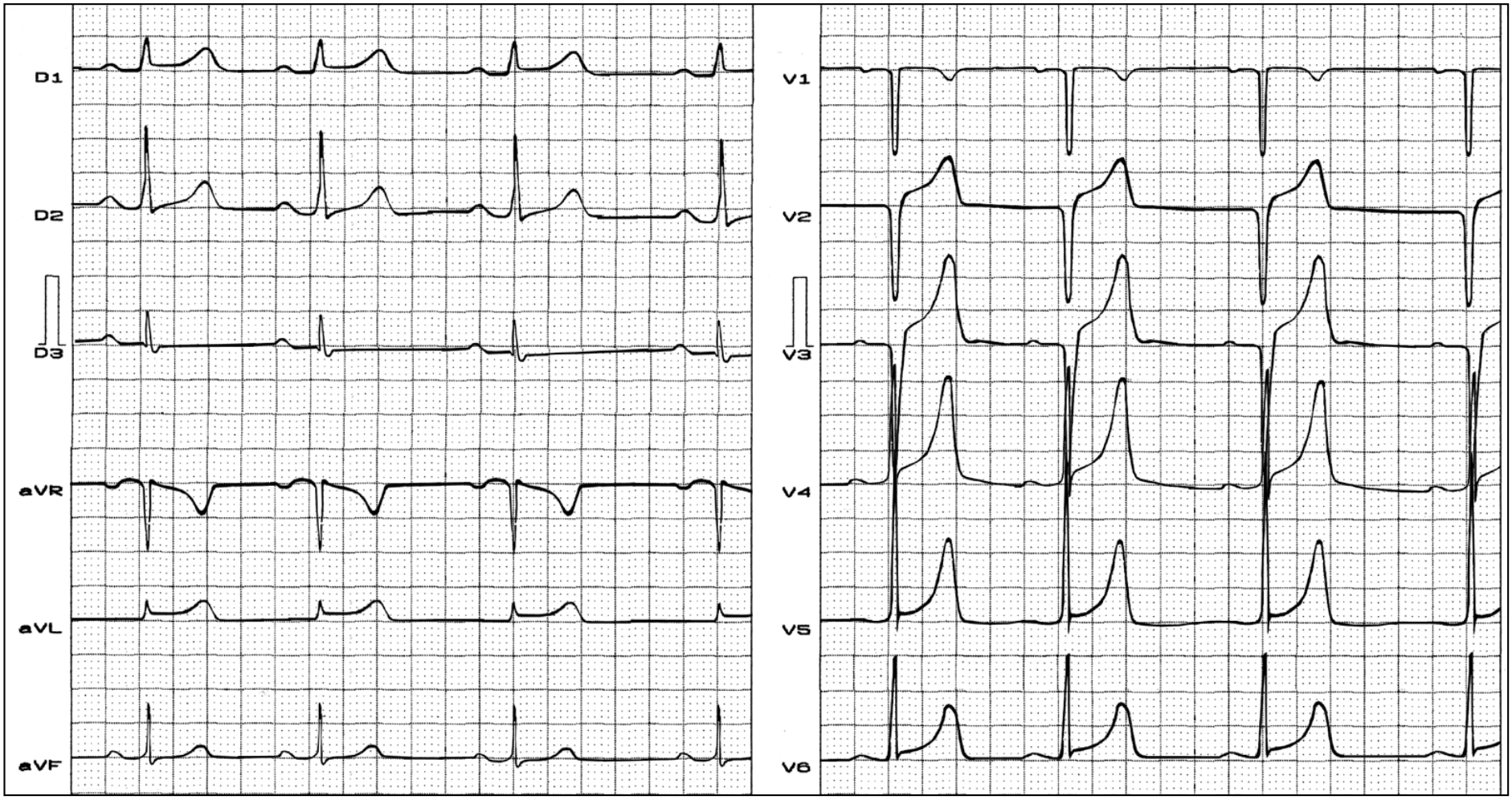
✓ Absence of reciprocal or mirror image (exception in VR lead);

✓ Symmetrical T waves, with great width and polarity matching QRS.




- HR: 53 bpm: Predominant sinus bradycardia is observed in early repolarization pattern (ERP). ERV is seen in individuals with high vagal tone, such as athlete's heart. QRS duration of 90 ms.
- QRS axis +40º.
- At least two adjacent precordial leads show ST segment elevation, with values ≥1 mm (2mm). Notching, irregular or slurring contour of the terminal QRS complex (J point).
- Relatively deep but narrow q waves may appear in the left precordial leads.
- Positive Sokolow index. High QRS voltage is more frequent in male athletes, but its correlation with left ventricular hypertrophy is low **(our case)**. This young man is a professional soccer player.
- Prominent J wave and ST-segment elevation, concave to the top, predominantly in left precordial leads, ending in a positive large T wave from V2 to V4 or V5.
- Prominent U waves are observed because sinus bradycardia is present.

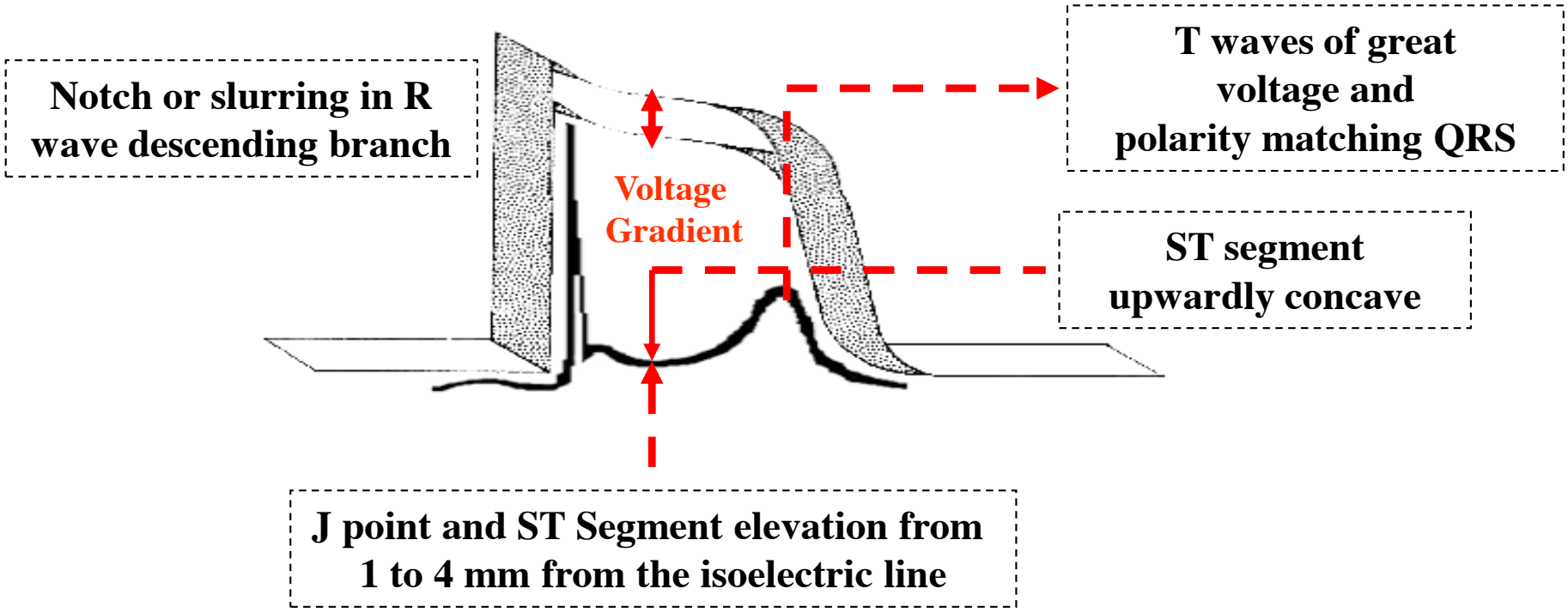
**Name:** BCA **Age:** 22yo **Sex:** Male **Race:** Black **Weight:** 82 kg
**Height:** 1.96m **Biotype:** Athletic Profession: professional basketball player **Date:** 2/09/2001




**Clinical diagnosis:** athlete's heart. Normal variant.
**ECG diagnosis:** sinus rhythm; HR: between 50 bpm and 57 bpm: phasic or respiratory sinus bradyarrhythmia; QS from V1 to V3: pattern of pseudo infarction in antero-septal wall. Peaked T waves from V3 to V6. Normal X-rays of chest and echocardiogram.

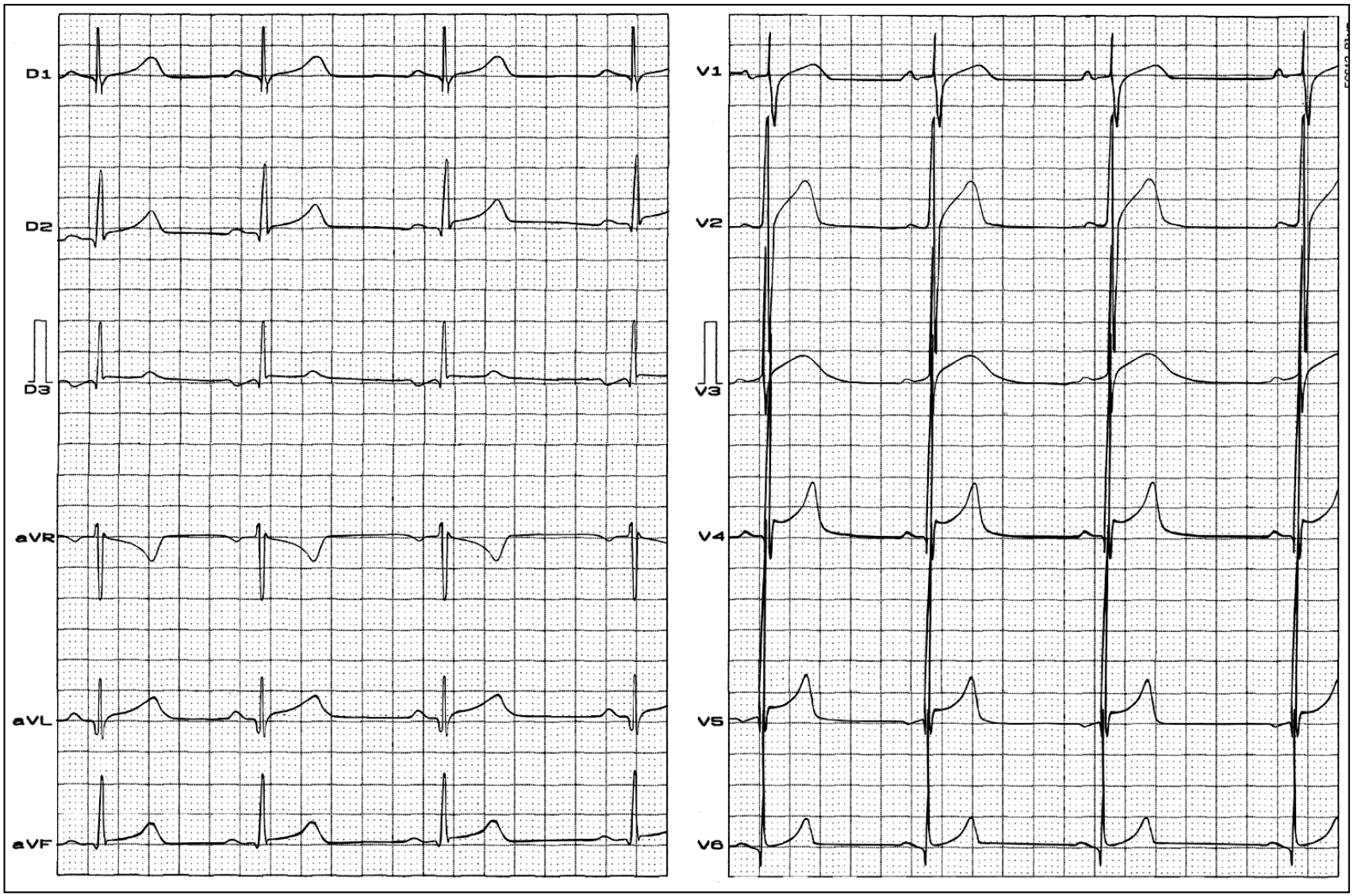
Pattern of pseudo anterior infarction in an athlete, professional player of basketball with normal heart.

In early repolarization, there is a voltage gradient, however, no dispersion of duration of action potentials in ventricular wall thickness. For this reason, these patients showed ST segment elevation with no tendency to develop arrhythmias.




Theoretical electrophysiological explanation for ST segment elevation in ECGs in athletes.

**Name:** ALK **Age:** 27y **Sex:** Male **Race:** White **Weight:** 70 kg
**Height:** 1.71m **Biotype:** Athletic **Profession:** Athlete




**Clinical diagnosis:** normal variant in elite athletes in the modality of hurdles.
**ECG diagnosis:** Rhythm: sinus bradycardia, phasic sinus arrhythmia. HR: between 48 and 55 bpm. Discrete ST segment elevation, upwardly convex from V4 to V6 and inferior leads. Prominent q wave in these leads.

Typical ECG of an elite athlete, showing bradycardia and early repolarization syndrome.

# Most frequent characteristics of ECG in athletes

1. **1) Rhythm:**
    - Sinus, junctional or rarely ventricular.
    - Variable pacemaker or rhythm of left atrium.
    - Junctional rhythm is present in 0.31% (in the general population in 0.02%).
    - Phasic or respiratory sinus arrhythmia: present in 60% (in the population non athletes in 2.4%).
    - Long sinus pauses: they are frequent (> 2 seconds);
2. **Heart rate:**
    - Sinus bradycardia in more than 50% of the cases.
    - HR of 30 to 40 bpm in rest are not rare.
    - In highly trained athletes, there are descriptions of HR of 25 bpm. **Etiology:** vagal hypertone; decrease in resting sympathetic tone; and intrinsic component of bradycardia;
3. **P Wave:**
    - Increase of voltage and notches are described;
4. **PR Interval:**
    - 1st degree AV block: 5% and 30% (in non athletes, 0.65%). When the PR interval does not reach the value as a criterion for 1st degree AV block, it is relatively prolonged. The PR interval normalizes or even gets smaller after exercise;
    - 2nd degree AV block:
    - a) Mobitz Type I or Wenckebach: it is observed in 10% (in non athletes < 1 in 30,000 or 0.003%), and it disappears invariably during exercise and atropine;
    - b) Mobitz Type II;
    - AV dissociation;
    - Complete or 3rd degree AV block: 5 each 12,000 athletes.

5. **QRS:**SAQRS: tendency to vertical position; Possible presence of voltage criteria for LVH: SV1+RV5 > 35mm (Sokolow and Lyon index); Possible pattern of RVH: RV1+SV5 >10.5 mm between 18% and 69% of the cases. RVH manifests by a diastolic pattern translated by minimal degrees of IRBBB. The IRBBB is observed in 15% of athletes; Absence of progression of increase of voltage of r or R wave with QR pattern from V1 to V3: pattern of pseudo infarction in anterior wall. Pattern of CRBBB: observed in 13.5% of the cases;

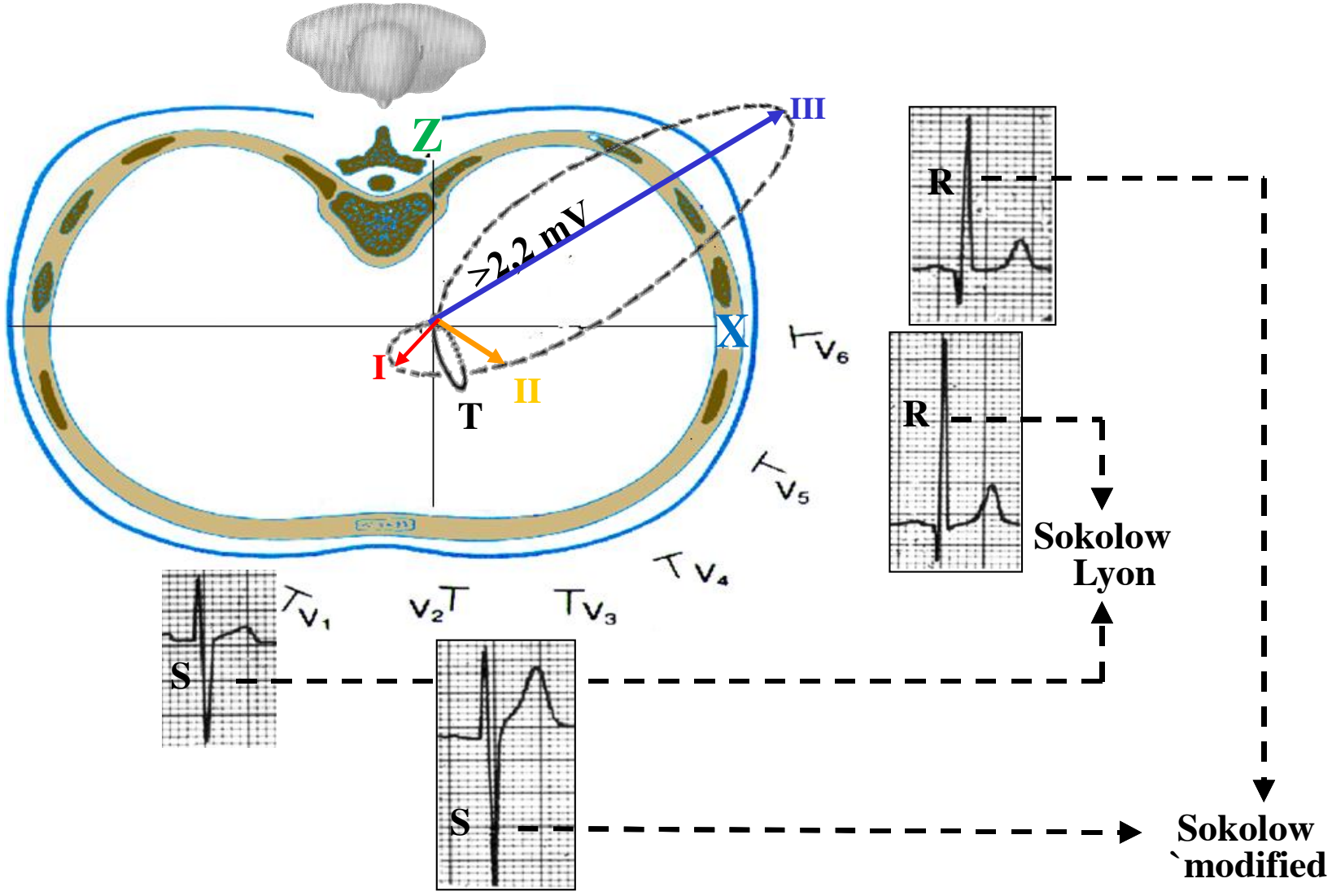
6. **Ventricular repolarization: ST segment** Pattern of early repolarization variant; It is described in four patterns:
    - J point and ST segment elevation followed by peaked T wave from V4 to V6 and in the inferior wall (2.4% to 44%);
    - J point and ST segment depression (rare);
    - J point and ST segment elevation followed by inverted T wave;
    - Disappearance of ST segment elevation after exercise.

7. **Ventricular repolarization: T wave:** Juvenile pattern of T wave. Inverted and asymmetrical T wave in left leads: I, aVL, V5 and V6, secondary to physiologic LVE. Negative or biphasic T waves from V1 to V3 and/or in the inferior wall. Frequent "normalization" of T wave before strain. This type of response is not observed in hypertrophic cardiomyopathy or in coronary insufficiency. Myocardial perfusion imaging associated to exercise stress test always negative. Characteristic reversion of ECG "alterations" in cases of interruption of competitive activity.

8. **U wave:** After the T wave, a rounded deflection is observed mostly in precordial leads V3 and V4, called U wave. Usually, it has the same polarity as T wave. It is always, in normal cases, positive in I, II and from V2 through V6. Its amplitude is inversely proportional to HR, being greater in athletes with bradycardia, and smaller in children with tachycardia.

# Isolated voltage criterion for LVH: Sokolow-Lyon index modified for LVH

## S of $V_2$ + R of $V_5$ or $V_6 \geq 35$ mm



12. Junctional rhythm.

13. Atrial fibrillation (AF) and atrial flutter are facilitated by atrial remodeling, atrial ectopy, and an imbalance of the autonomic nervous system. Endurance sports practice has an impact on all of these factors and may therefore act as a promoter of these arrhythmias. In an animal model, long-term intensive exercise training induced fibrosis in both atria and increased susceptibility to AF. While the prevalence of AF is low in young competitive athletes, it increases substantially in the aging athlete, which is possibly associated with an accumulation of lifetime training hours and participation in competitions. A recent meta-analysis revealed a 5-fold increased risk of AF in middle-aged endurance athletes with a striking male predominance Beside physical activity, height and absolute left atrial size are independent risk factors for lone AF and the stature of men per se may explain part of their higher risk of AF. Furthermore, for a comparable amount of training volume and performance, male non-elite athletes exhibit a higher blood pressure at rest and peak exercise, a more concentric type of left ventricular remodeling, and an altered diastolic function, possibly contributing to a more pronounced atrial remodeling. The sports cardiologist should be aware of the distinctive features of AF in athletes. Therapeutic recommendations should be given in close cooperation with an electrophysiologist. Reduction of training volume is often not desired and drug therapy not well tolerated. An early ablation strategy may be appropriate for some athletes with an impaired physical performance, especially when continuation of competitive activity is intended.

# Atrial Fibrillaton in Athletes

Lone atrial fibrillation: AF in absence of any clinical evidence of cardiac or extra cardiac factor such as latent hypertension, coronary artery disease, chronic obstructive lung disease, valvular disease, cardiomyopathy, diabetes, hyperthyroidism. obesity, metabolic syndrome, sleep apnea, alcohol consumption, endurance sports, anger, hostility, subclinical atherosclerosis, inflammation. etc

≤ 60 years AF is exceptional in children, uncommon in young adults, but 3 to 4% of subjects over 60 years of age.

Possibilites

**Long-term endurance exercise**

Athlete mem with AF

The proportion of sportsmen among patients with lone AF is much higher than that reported in the general population

1. lower incidence of mild hypertension
2. AF vagal mediate

Echocardiogram: greater atrial and ventricular dimensions higher ventricular mass (**Mont 2002**).

Idiopathic, criptogenetic, essential, primary truly lone AF

30% of patients with paroxysmal AF

It is the effect of an underlying, 'masked' disorder.

It has a favorable prognosis

Embolic risk of 2 to 5% per year.

**Genetic causes Familial genetic predisposition**

Epidemiological studies have provided unequivocal evidence that the arrhythmia has a substantial heritable component.

Autosomal dominant pattern,

1. Mutations in K+ channel genes: congenital SQTS mutations *KCNE2*, *KCNJ2*, and *KCNQ1*
2. Common AF-associated 4q25 polymorphisms (**Ritchie 2012**)
3. Brugada syndrome
4. Sinus node dysfunction (see next slide)

# Atrial Fibrillation genetic mutations background: Mechanistic Sub classification of Lone Atrial Fibrillation (Robert 2010)

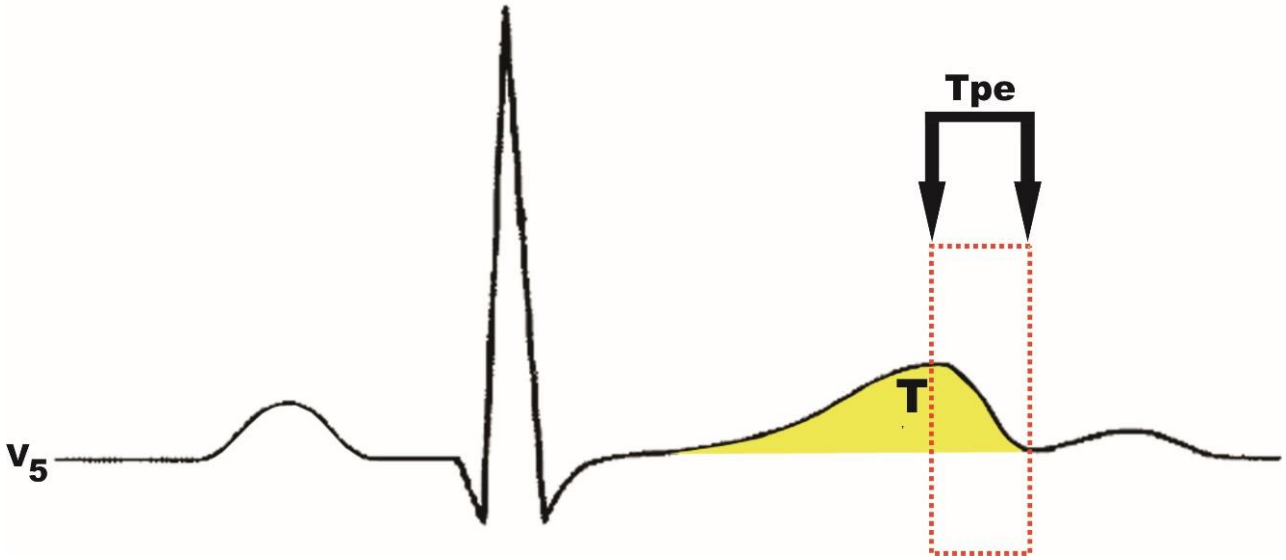
| AF subclassification | Culprit Gene | Functional effect |
|---|---|---|
| Enhanced atrial action potential repolarization | KCNQ1<br>KCNE2<br>KCNJ2 (**Xia 2005**)<br>KCNE5 (**Rayn 2008**) | Enhanced slow component of the delayed rectifier K+ current (Iks).<br>Enhanced KCNQ1 (**Das 2009; Chen 2003; Lundby 2007**) - KCNE2 K+ (**Yang 2004**) current<br>Enhanced inward rectifier current ($I_{k1}$)<br>Enhanced $I_{ks}$ |
| Delayed atrial action potential repolarization | KCNA5<br>SCN5A(**Makiyama 2008; Watanabe 2009; Darbar 2008**) | Decreased ultrarapid component of the delayed rectifier potassium current ($I_{kur}$). (**Yang 2009; Olson 2006**)<br>Hyperpolarizing shift in Na, 1.5 inactivation. |
| Conduction velocity heterogeneity | GJA5 (**Gollob 2006**) | Decreased Gap Junction conduction (**Delmar 2000**) |
| Cellular hyper excitability | SCN5A<br>(**Li 2009**) | Depolarizing shift in Na, 1.5 inactivation. |
| Hormonal modulation of atrial electrophysiology<br>Adrenocholinergic stimulation (**Yamazaki 2009**) | NPPA | Increased circulating levels of mutant atrial natriuretic peptide (**Hodgson-Zingman 2008**) |
| Cholinergic | Unknown | Enhanced cholinergic sensitivity A greater abundance of Kir3.x channels and higher $I_{(K,ACh)}$ density in LA than RA myocytes result in greater ACh-induced speeding-up of rotors in the LA than in the RA, which explains the ACh dose-dependent changes in overall AF frequency and wavelet formation (**Sarmast 2003; Rudy 2004**). |
| Locus on chromosome 10q22-q24<br>Gene Map locus on chromosome 4(4q25) | ATFB1<br>ATFB5 (**Gudbjartsson 2007; Benjamin 2009; Kääb 2009; Ellionor 2010; Husser 2010**) | Type 1 familial AF (**Brugada R 1997**) |
| Locus on chromosome 16q22 | ZFHX3 | (**Gudbjartsson 2009**) |
| ATP-binding cassette sub-family A member 1 | Chromosome: 9; Location: 9q31.1<br>(Chen 2009) | Cholesterol efflux regulatory protein |

**Arrhythmias in the hearts of athletes and comparative incidence with the general population**

| Arrhythmia | General population | Athletes |
|---|---|---|
| Sinus Bradycardia | 23.7 | 50-85 |
| Phasic Sinus Arrhythmia | 2.4-20 | 13.5-69 |
| Atrial Variable Pacemaker | Not available | 7.4-19 |
| 1st degree AV block | 0.65 | 6-33 |
| 2nd degree AV block | < 1 in 30,000 or 0.003%), | 10% |
| Mobitz Type 1 | 0.003 | 0.125-10 |
| Mobitz Type II | 0.003 | Not reported |
| 3rd degree AV block | 0.0002 | 0.017 |
| Junctional Rhythm | 0.06 | 0.31-7.0 |

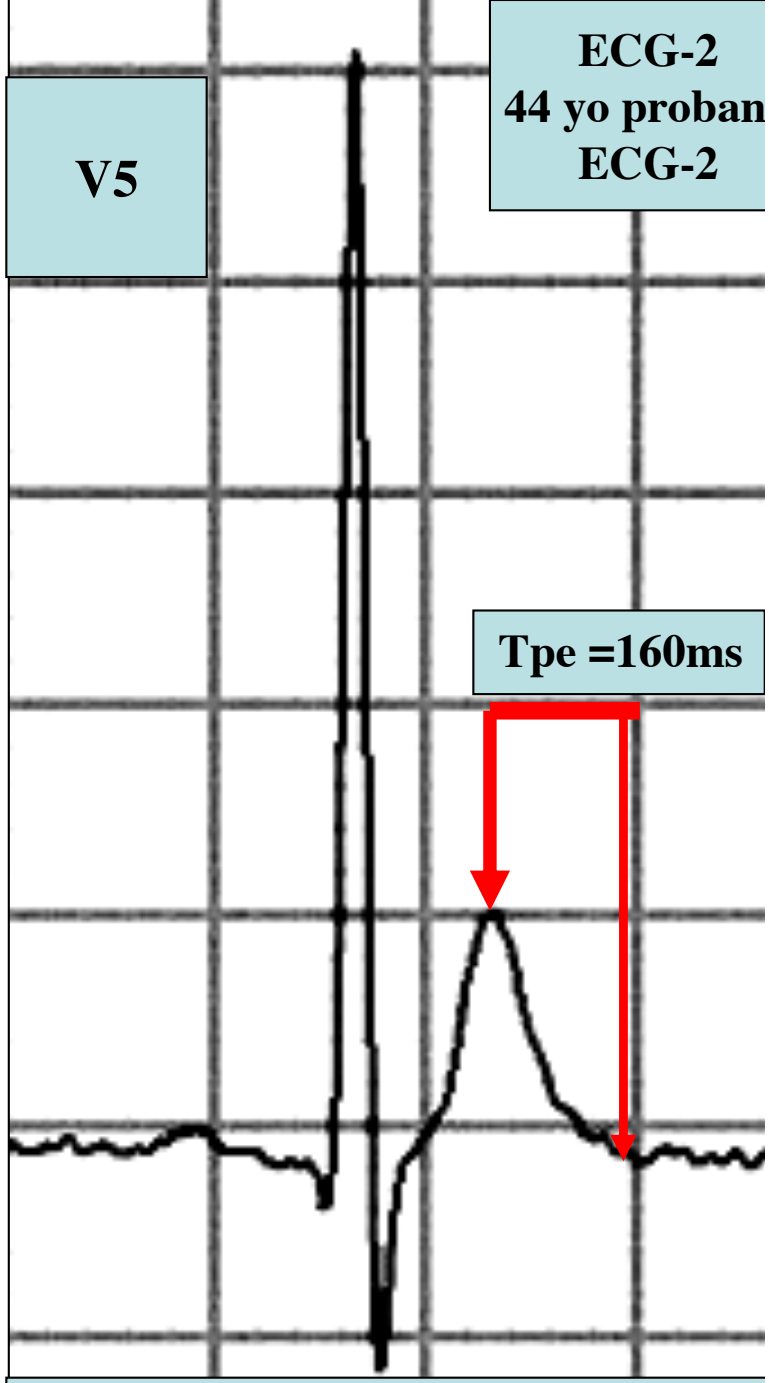
Table comparing the incidence of arrhythmias in the general population and in athletes.

The normal value of Tpeak/Tend interval (Tpe) is 94 ms in men and 92 in women when measured in the V5 lead. Tpe prolongation to values ≥120 ms is associated to a greater number of events in patients carriers channelopaties. In experimental models of SQTS, increased transmural dispersion of repolarization (TDR) and its electrocardiographic counterpart T-wave peak to T-wave end interval (TPE) appeared critical for induction of polymorphic ventricular tachycardia (**Anttonen 2008**).



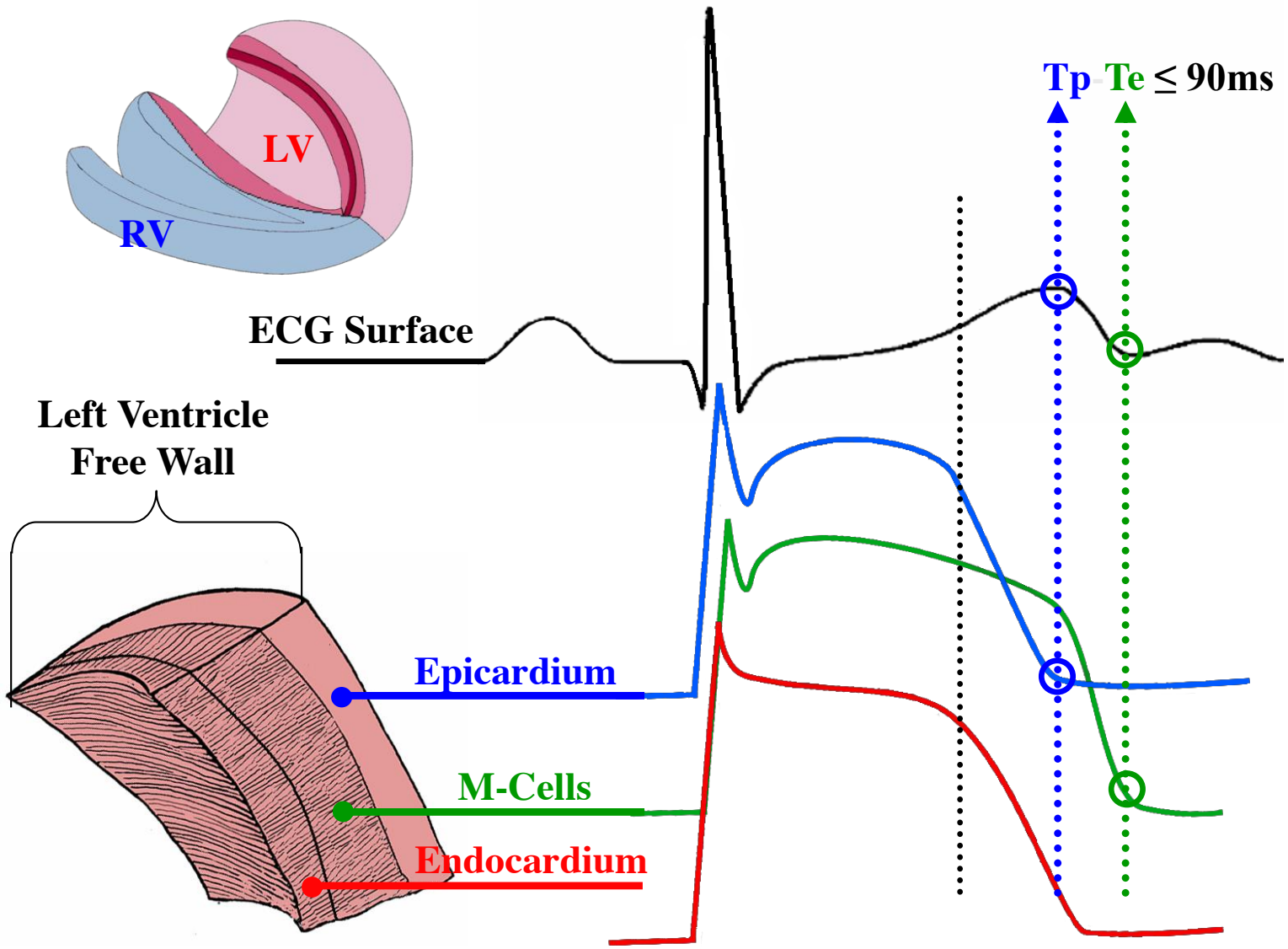

**Tpeak/Tend interval (Tpe)**

Interval elapsed from the apex to the end of T wave (Tpeak-Tend interval or Tpe). Tpe may correspond to transmural dispersion of repolarization and consequently, the amplification of this interval is associated to malignant ventricular arrhythmias.




**Very broad Tpe interval indicati singnificative transmural dispersi of repolarization**

# T-peak to T-end interval (TpTe)




Distance between the T-peak/T-end Normal value ≤ 90ms It is prolonged from 90 to 130ms in the global transmural dispersion cases. In this circumstance is observed:

- QT interval prolongation from 350 to 450 milliseconds
- T-peak to T-end interval (TpTe) prolongation
- T-wave notches appeared in very limited precordial leads.

# Summary of the ECG elements common in athletes

1) Sinus bradycardia.
2) Sinus arrhythmia.
3) P wave with notches and of greater voltage.
4) 1st degree AV block: 6% to 36%.
5) 2nd degree AV block, Wenckebach type: Mobitz Type I (0.125% to 10%).
6) IRBBB or end conduction delay.
7) Voltage or axis criterion for RVH.
8) Voltage criterion for LVH.
9) Early repolarization variant
10) J point and ST segment elevation or depression.
11) QT interval in the superior borderline of normality.
12) T wave of increased voltage, peaked and inverted.
13) Atrial fibrillation and flutter (**Furlanello 1998**).
14) Junctional rhythm.

## II) Ergometer test or exercise electrocardiography with or without spirometry

It is an electric recording of the heart while the organism is undergoing physical stress. The most used ergometers are the bicycle ergometer and the treadmill. It should be performed in all preventive medicine check-ups, but regrettably, it is not so. But it is convenient for all athletes or at least sportsmen with a regular activity, to do this test. Only thus it is possible to know how the heart behaves regarding physical strain. In sedentary people older than 30 years old, who begin a program of exercises, it should be mandatory. It is known that 70% of people with chest angina and who hadn't experienced myocardial infarction, present rest ECG without abnormalities, and that many myocardial ischemias appear in a strain test even before the person has displayed any symptom. Although test characteristics of exercise electrocardiography are well established in symptomatic patients, data on healthy athletes are scarce. Van de Sande et al studied a systematic review focuses on the diagnostic utility of exercise electrocardiography for the detection of CAD in athletes during pre-participation screening. This systematic review evaluated the prevalence of an abnormal exercise test result and the positive predictive value of exercise electrocardiography in asymptomatic athletes. In addition, the long-term prognosis of a false-positive test result was evaluated. This systematic review revealed a relatively low prevalence of positive exercise test results in asymptomatic athletes, but a very poor positive predictive value. There were insufficient data available to determine the prognostic implications of false-positive test results in asymptomatic athletes (**van de Sande 2016**).

## III) High resolution electrocardiography(HRECG) or Signal-Averaged Electrocardiogram (SAECG)

Presence of late potentials (LPs) are observed in ≈ 10% of the cases in the population of athletes against 1.4% in the general population (**Borbola 1992**).

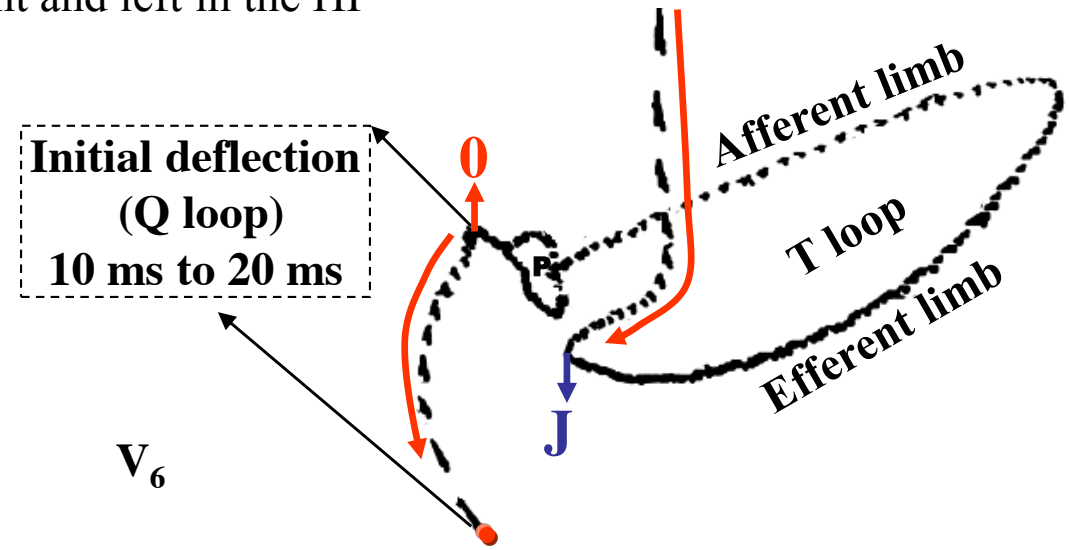
SAECG is acquired according to accepted methodology with the same machines used for standard ECG, with use of a 40-Hz high-pass bidirectional filter (**Cain 1996**). LPs are defined as abnormal values in ≥1 of the following parameters (in accordance with current diagnostic criteria for ARVC) (**Marcus 2010**):

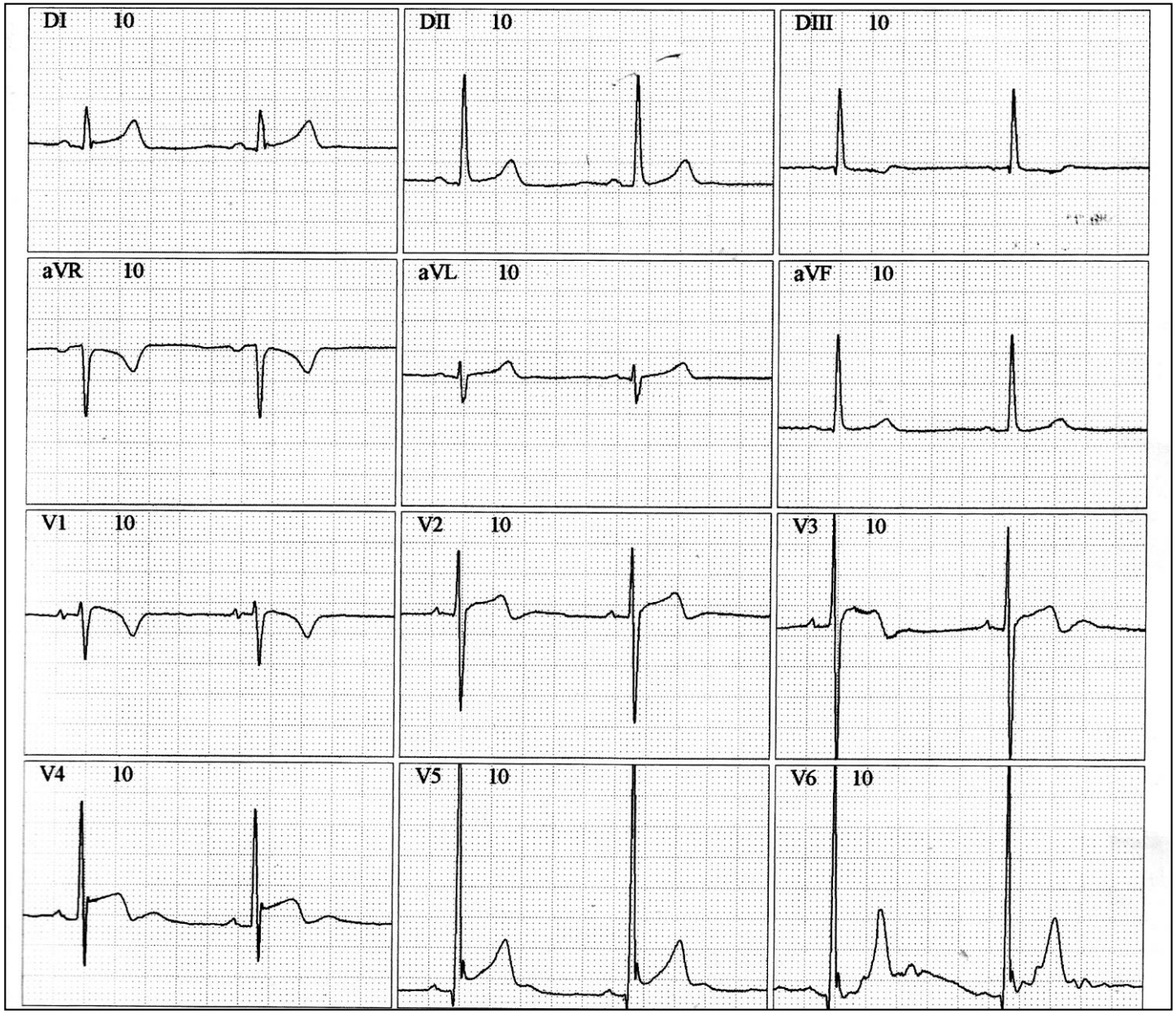
I. Duration of filtered QRS complex >114 ms (with QRS duration <110 ms on standard ECG),
II. Duration of terminal QRS (with amplitude <40 μv) >38 ms,
III. Root-mean-square voltage of the terminal 40 ms of filtered QRS <20 μv.

## IV) Vectorcardiogram (Zenner 1982; Pérez-Riera 2013)

In athletes we can observe:

- Increase of anterior forces in almost all cases
- Dislocation of QRS loop to the front and left in the HP
- T loop not matching QRS loop.
- 0 & J points are coincident.






**Clinical Diagnosis:** Professional soccer player athlete's heart.

**Name:** VLAS **Gender:** M

**Age:** 16yo. **Ethnic group:** Mulatto

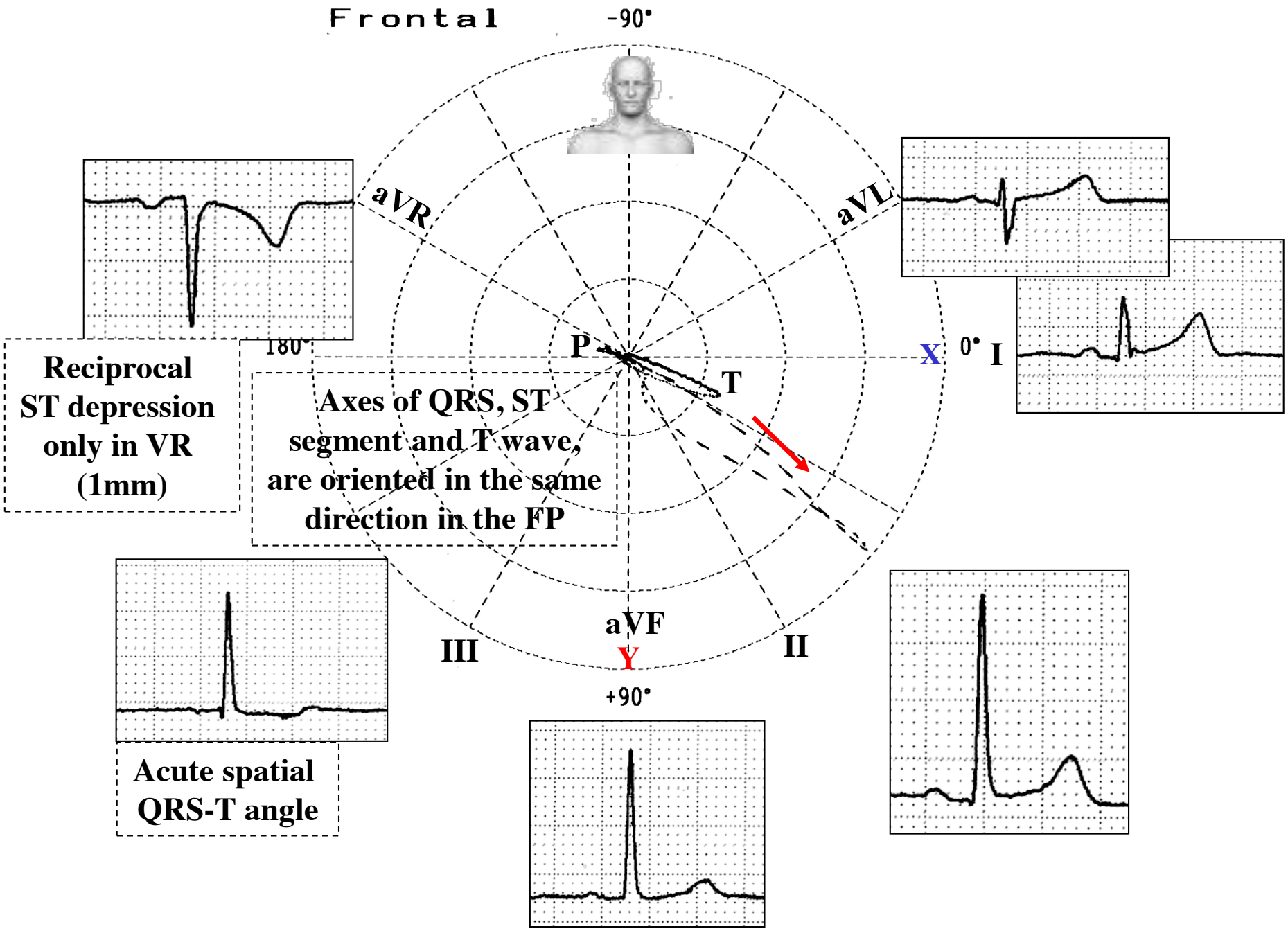
**Weight:** 65Kg **Height:** 1,73

**Biotype:** Normoline **Date:** 04/11/2008

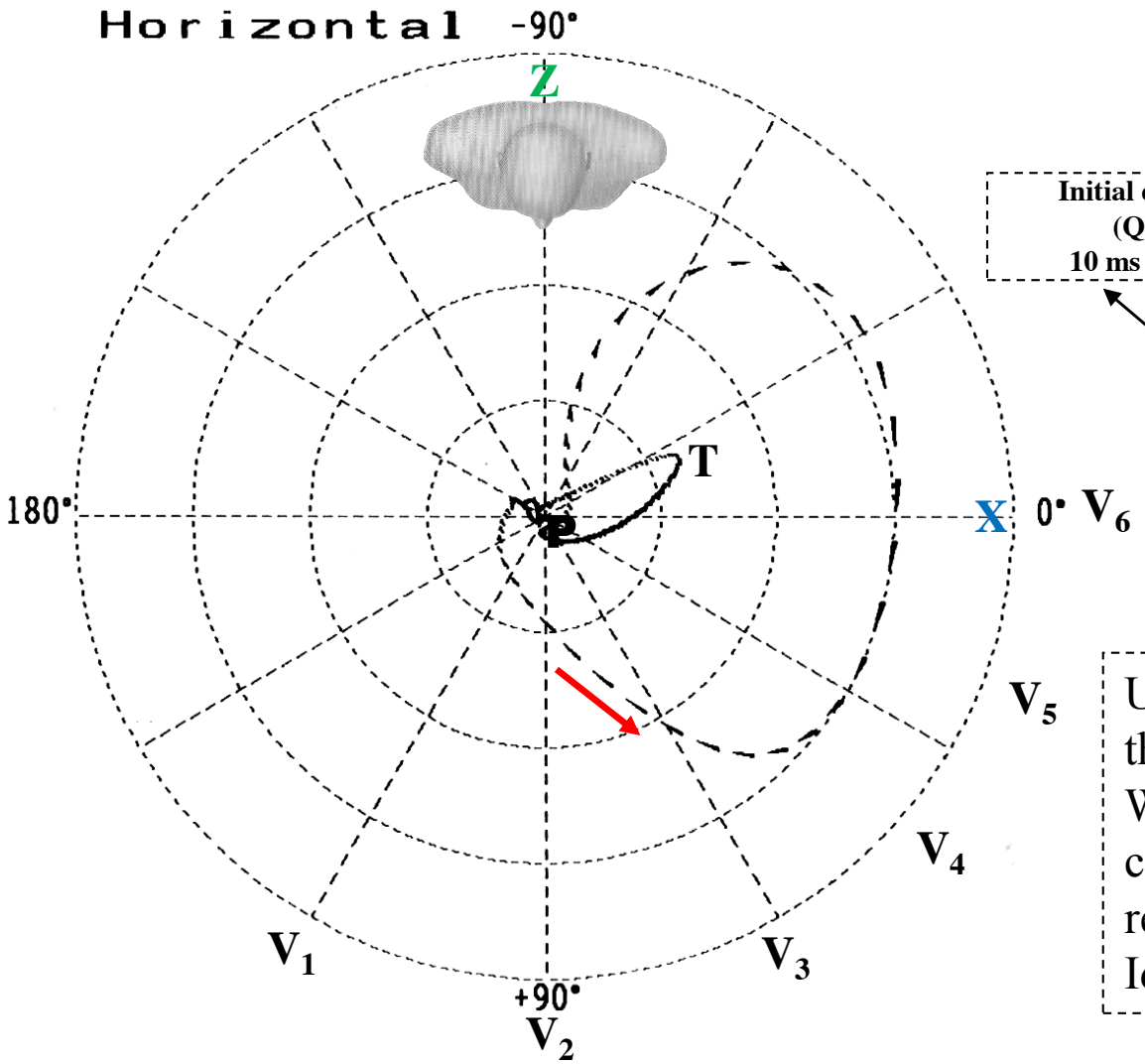
**ECG diagnosis:**

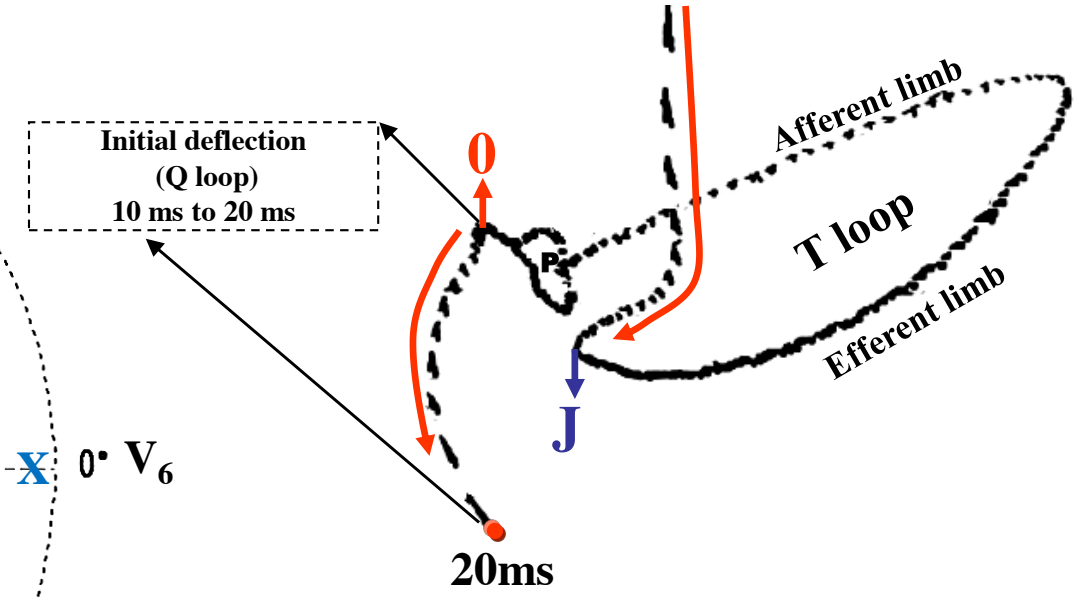
- HR: 53 bpm: Predominant sinus bradycardia is observed in early repolarization pattern. ERV is seen in individuals with high vagal tone, such as athlete's heart. QRS duration of 90 ms.
- QRS axis +40º
- At least two adjacent precordial leads show ST segment elevation, with values ≥1 mm (2mm). Notching, irregular or slurring contour of the terminal QRS complex (J point).
- Relatively deep but narrow q waves may appear in the left precordial leads
- Positive Sokolow index. High QRS voltage is more frequent in male athletes, but its correlation with left ventricular hypertrophy is low **(our case)**. This young man is a professional soccer player.
- Prominent J wave and ST-segment elevation, concave to the top, predominantly in left precordial leads, ending in a positive large T wave from V2 to V4 or V5.
- Prominent U waves are observed because sinus bradycardia is present.

# ECG/VCG frontal plane correlation



# VCG horizontal plane correlation



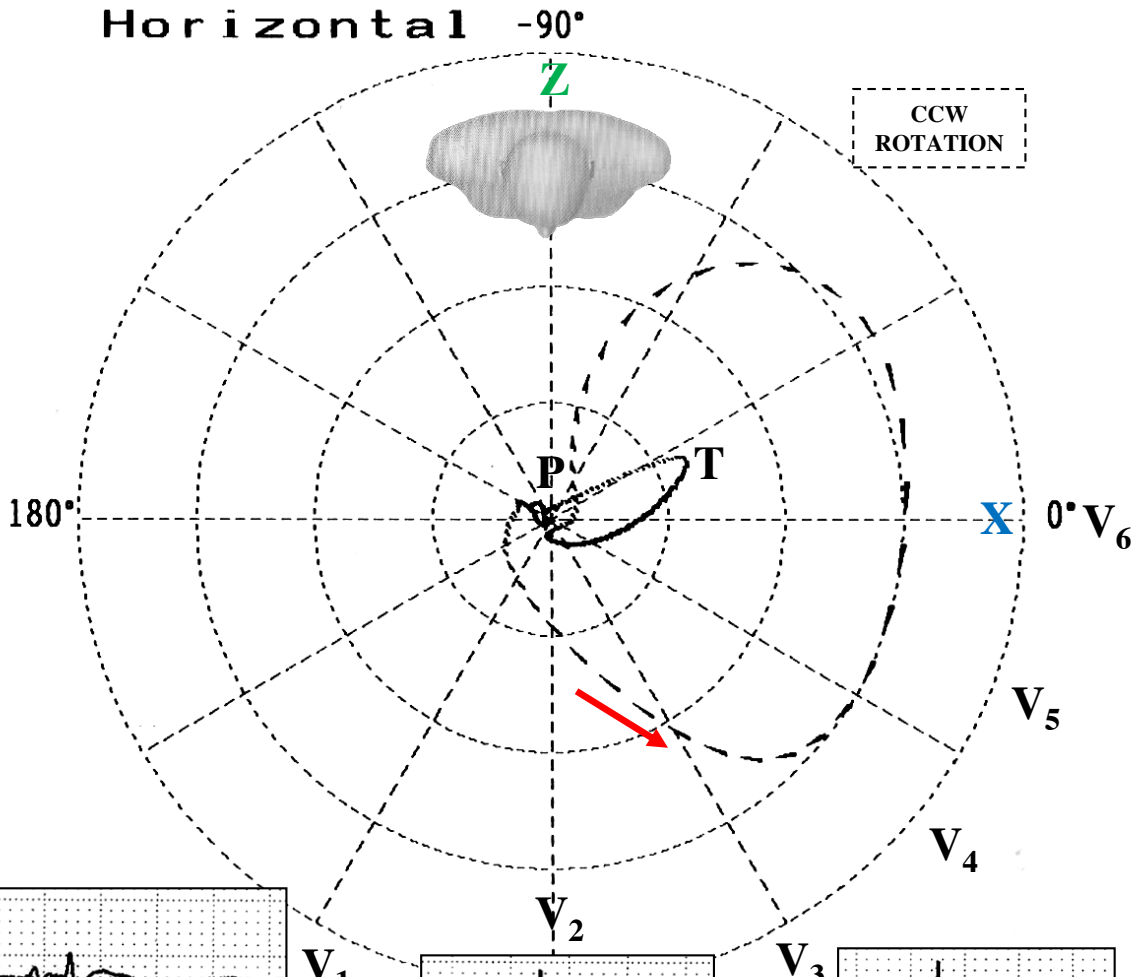



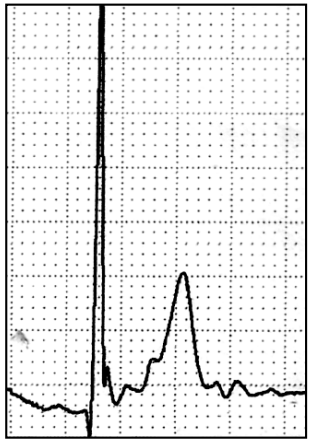

Usually 0 & J points are coincident. In this case, they are not: ST-segment elevation
When ST is elevated, the J and 0 points do not coincide: we observe this phenomenon in early repolarization pattern, Brugada syndrome, Idiopathic VF, and short QT syndrome

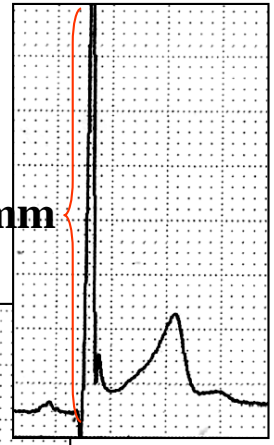
**0 point:** it corresponds to the end of biatrial chamber activation, QRS loop onset (because PR segment does not exist, it is only a point) and the end of ventricular repolarization (T loop).

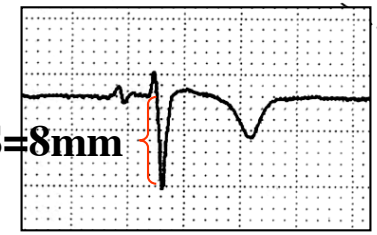
**J point:** in vectorcardiography, it corresponds to 3 elements: end of ventricular depolarization (QRS complex); beginning of repolarization (ST segment) when it does not present depression or elevation, and T wave onset.

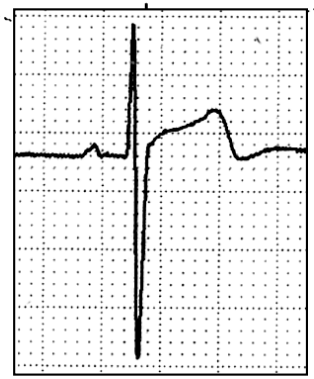
# ECG/VCG horizontal plane correlation

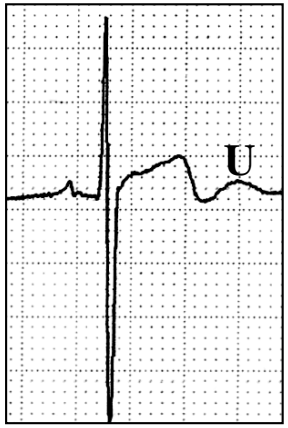


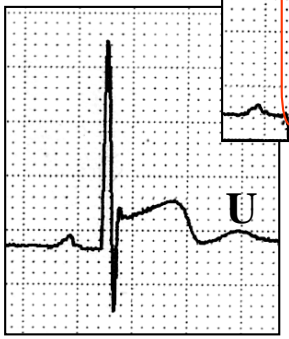





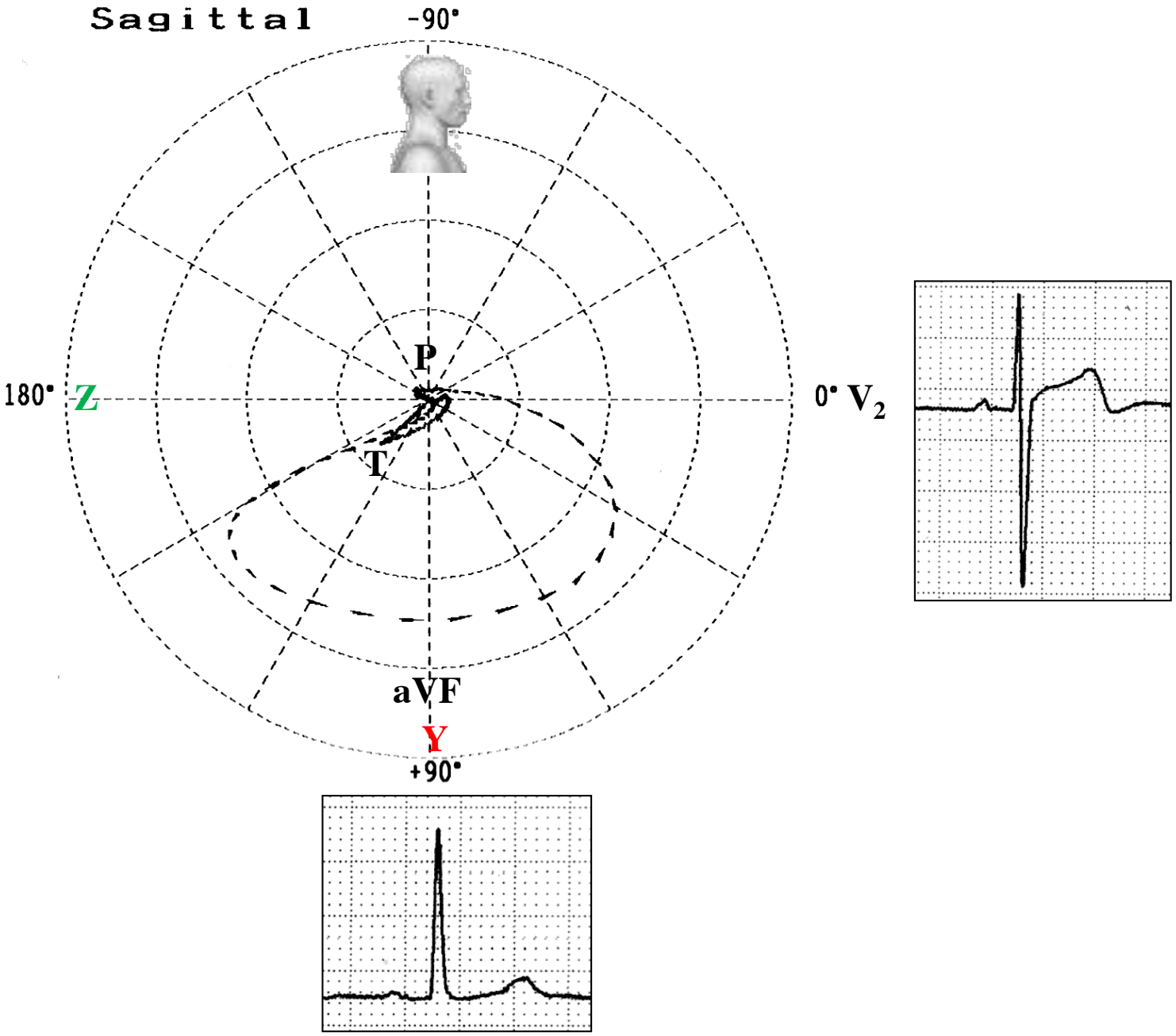





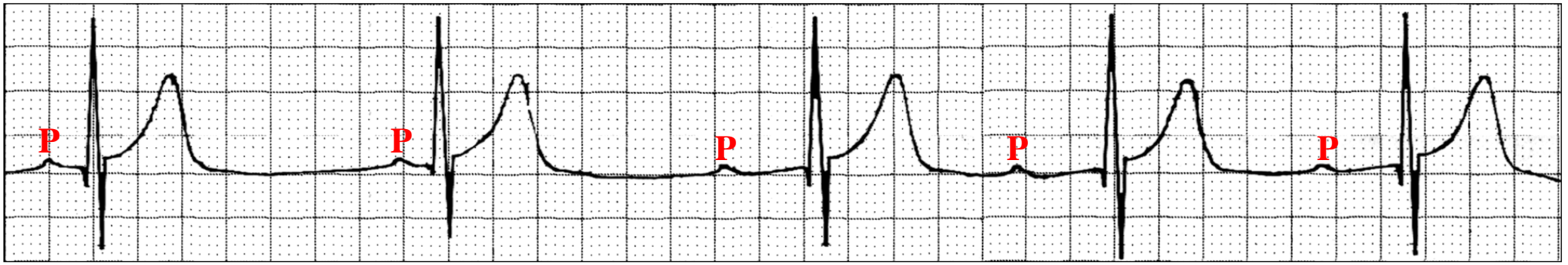

$SV_1+RV_5$ = 44 mm (maximum value 35mm) (positive Sokolow & Lyon criteria for left ventricular hypertrophy)

# ECG/VCG right sagittal plane correlation



# V) Holter monitoring Long-term ECG (long-term electrocardiogram)
# Holter recording 1ST degree AV block

**Name:** B . C. **Sex:** Male **Age:** 22 **Race:** Black **Weight:** 74 Kg.
**Height:** 1.82 m **Biotype:** Athletic **Date:** 01/04/2002
**Time:** 2:50:12 AM Patient sleeping. **Profession:** Marathon runner



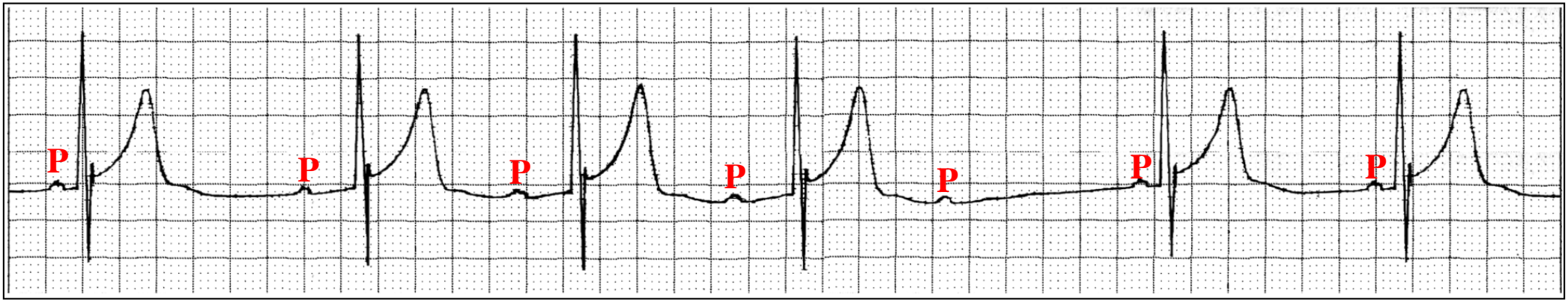

Heart rate of 38 bpm.
1st degree AV block usually observed for a few seconds, as in this case, where it is present only in the three last beats.

1st degree AV block is observed in average between 10% and 33% of athletes (**Smith 1964**), generally very briefly. In non-athletes it is around 0.65%.

1st-degree AV block in an elite athlete in Holter.

# Holter recording

**Name:** A . S. **Sex:** Male **Age:** 26 **Race:** Black **Weight:** 64 Kg.
**Height:** 1.68 m **Biotype:** Athletic **Date:** 05/01/2003
**Time:** 3:42:30 AM Patient sleeping. **Profession:** long distance runner



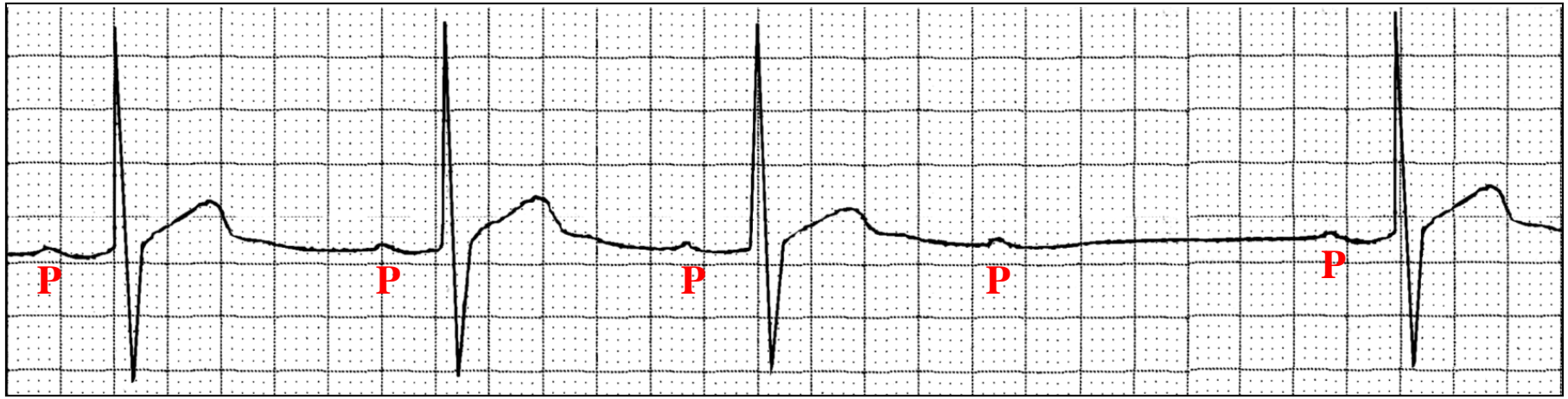

Gradual prolongation of PR interval until the 5th P wave is not conducted: 2nd degree AV block; Wenckebach or Mobitz Type I.

This modality of dromotropic disorder is observed in more than a 20% of elite athletes (**Viitasalo 1982**). In the general population, 2nd degree AV block Type I & II is observed and 1 each 30,000 people or 0.003 %

2nd-degree AV block, Wenckebach type or Mobitz Type I in an elite athlete.

# Holter recording 2nd degree AV block, Mobitz type II with narrow QRS

**Name:** E . J. **Sex:** Male **Age:** 26 **Race:** White **Weight:** 70 Kg.
**Height:** 1.72 m **Biotype:** Athletic **Date:** 25/01/2001 **Time:** 1:52:10 AM Patient sleeping
**Profession:** Long distance runner

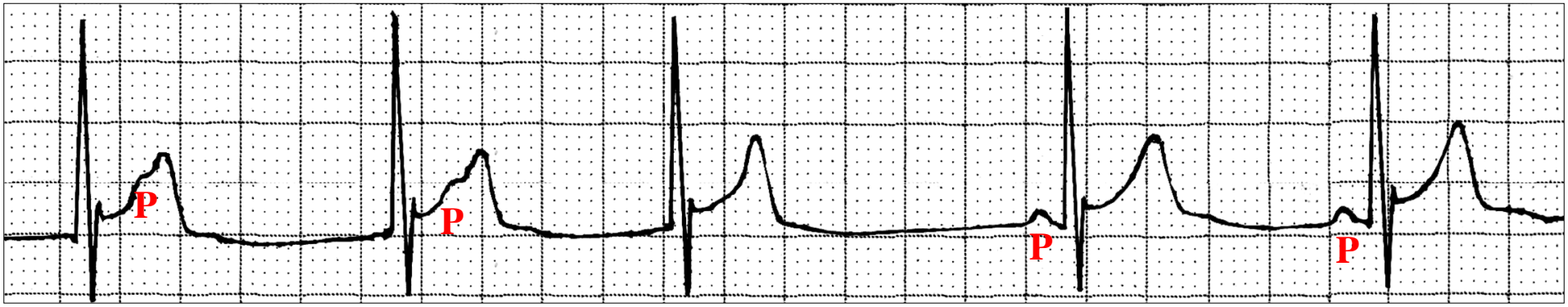



PR interval remains constant until a P wave is not conducted. This type of block is observed in 7% of the cases in athletes of enduro. Fixed or constant PR interval: it does not exist, progressive prolongation of PR, with the block occurring suddenly. In general, 2nd degree AV block type II with narrow QRS is observed in 35% of the cases and in the remaining 65%, the QRS is long.

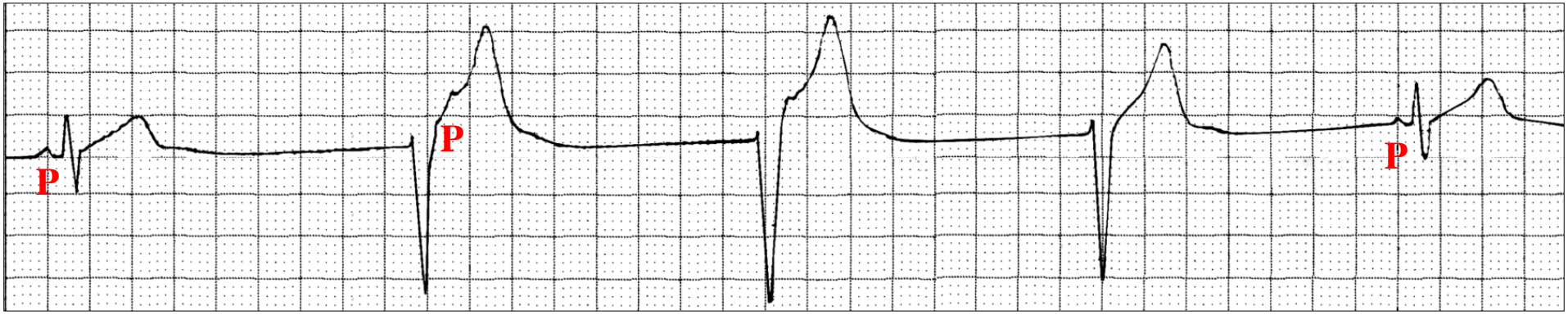
2nd-degree AV block, Mobitz type II with narrow QRS.

# Holter recording

**Atrioventricular dissociation (dissociation by interference) with junctional scape rhythm**




**Atrioventricular dissociation (dissociation by interference) with scape ventricular rhythm**




Atrioventricular dissociation (dissociation by interference) with junctional scape rhythm and atrioventricular dissociation (dissociation by interference) with scape ventricular rhythm in an elite athlete in Holter.

## V) Others Non-invasive complentaries test

1. Transesophageal or biplanar echocardiogram or transesophageal echocardiography
2. Three-dimensional transoesophageal echocardiography (**Kamperidis 2014**)
3. Intracardiac echocardiogram
4. Heart rate variability (HRV), "RR variability" or “cycle length variability”
5. Microvolt T-Wave Alternans
6. Cardiovascular nuclear magnetic resonance, Cardiac Nuclear magnetic resonance, or heart magnetic resonance imaging (MRI)
7. Non-contrast CT for coronary artery calcium scoring (CACS), contrast-enhanced coronary CT angiography (CCTA), Ultra-fast computed tomography., radioisotopic ventriculography

## Invasive supplementary tests

1) Programmed electrophysiological stimulation (PES).
2) Cineangiography, coronary angiography, and ventricular angiography.
3) Endomyocardial biopsy.

# Concept of Sudden Death (SD) and prevalence in athletes

SD is defined as the death that is not traumatic, not violent, unexpected, which occurs within the first 6h without a prior manifestation of cardiac disease (**Maron 1986**).

**Prevalence**

Estimated between young athletes of secondary school, as 1 in 200,000 per year (**Maron 1996-1998**).

Concept and prevalence of sudden death in athletes.

# The causes of arrhythmic sudden death in young athletes < 35 years old (average age: 17 years)

## I. Entities with structural heart disease (98%)

1. Hypertrophic cardiomyopathy (HCM) whether in its obstructive form or in its non-obstructive form (36%);
2. Congenital anomalies of coronary arteries with increase of ventricular mass (19%);
3. Tumors or cardiac masses (10%);
4. Aorta rupture due to Marfan syndrome (5%). Mutation in the gene in fibrillin-1 (FBN1), in chromosome 15q21.1 and Marfan-like syndrome with no eye anomalies, mapped in chromosome 3p24;
5. Arrhythmogenic right ventricular dysplasia/cardiomyopathy (3%). Prevalence of 1 in 15,000;
6. Early atherosclerotic coronary artery disease (2%) by familial hypocholesterolemia and dominant mixed hyperlipidemia by alteration in chromosome 6;
7. Mitral valve prolapse syndrome (MVPS) (2%);
8. Myocarditis (2%);
9. Familial arrhythmogenic syndrome: ventricular and tachyarrhythmia association (syndrome of Wolff-Parkinson-White), progressive disease of conduction system and cardiac hypertrophy by involvement of regulatory subunit gamma-2 (PRKAG2) of AMP- activated by protein kinase (**Gollob 2002**);
10. Aortic stenosis.

Description of the causes for arrhythmic sudden death in young athletes (average age: 17 years old), secondary to structural heart disease.

# The causes of arrhythmic sudden death in young athletes (average age: 17 years)

**II) Entities without apparent structural heart disease (2%);**

1) Drug abuse, e.g. anabolic agents,

2) Ventricular pre-excitation of the Wolff-Parkinson-White syndrome type, with anomalous pathway of short refractory period, not detected previously;

3) Cardiac concussion or commotio cordis;

4) Channelopathies or primary electrical diseases.

Description of the causes for arrhythmic sudden death in young athletes (average age: 17 years old) without structural heart disease.

# Channelopathies or primary electrical diseases

**A) Of the sarcolemma or external channelopathies:**

1) Congenital long QT syndrome;

2) Brugada disease;

3) Progressive familial heart block type I; progressive “idiopathic” disease of the His-Purkinje system or Lenègre;

4) Genuine idiopathic ventricular fibrillation (GIVF);

5) Mixed forms or with overlapped phenotypic aspects:

5a) Brugada disease and variant 3 of congenital LQTS;

5b) Brugada disease and Lenègre disease;

5c) Brugada disease and sinus node dysfunction;

5d) Association of Brugada disease, LQTS and progressive conduction disorder;

6) Some sudden unexpected nocturnal death syndromes (SUNDS);

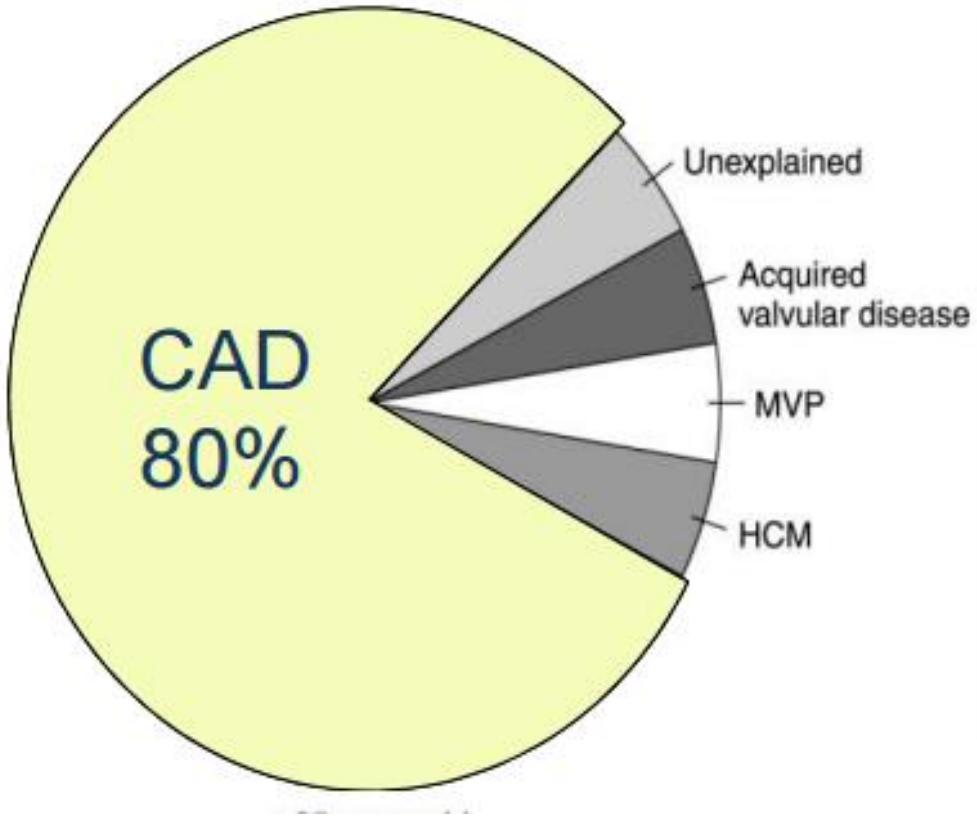
7) Some sudden infant death syndromes (SIDS).

**B) Of the channels of the endoplasmic reticulum or intracellular channelopathies:**

1) Catecholaminergic polymorphic ventricular tachycardia (CPVT).

Description of the causes for arrhythmic sudden death in young athletes (average age: 17 years old) without structural heart disease by channelopathies or primary electrical diseases.

## Causes of sudden death in competitive athletes > 35 years old (Maron 2007)




Most exercise-related cardiac arrests in men aged ≥45 years are due to coronary artery disease (CAD). The current sports medical evaluation (SME) of middle-aged sportsmen includes medical history, physical examination and resting and exercise electrocardiography. Braber et al (**Braber 2016**) investigated the added value of low-dose cardiac computed tomography (CCT) - both non-contrast CT for coronary artery calcium scoring (CACS) and contrast-enhanced coronary CT angiography (CCTA) - in order to detect occult CAD in asymptomatic recreational sportsmen aged ≥45 years without known cardiovascular disease. Coronary CT detects occult CAD in almost one in five asymptomatic sportsmen aged ≥45 years after a normal sports medical evaluation SME that included resting and bicycle exercise ECG. CACS reveals most of the relevant CAD with limited additional value of contrast-enhanced CCTA. The number needed to screen in order to prevent one cardiovascular event compares favourably to that of other screening tests.

# Structural, electrical an functional changes of physiological ventricular hypertrophy of athlete's heart (ventricular remodeling)

I. ***Electrical:*** *Bradycardia, phasic sinus arrhythmia, atrioventricular block, early repolarization pattern, voltage criteria for chamber enlargement*

II. ***Structural:*** *Increased chamber wall thickness and cavity size*

III. ***Functional:*** *Enhanced diastolic filling, augmentation of stroke volume*

***Dilemma***

False –positive diagnoses and lead to erroneous disqualification from a sport with significant psychological distress and loss of earnings.

Versus

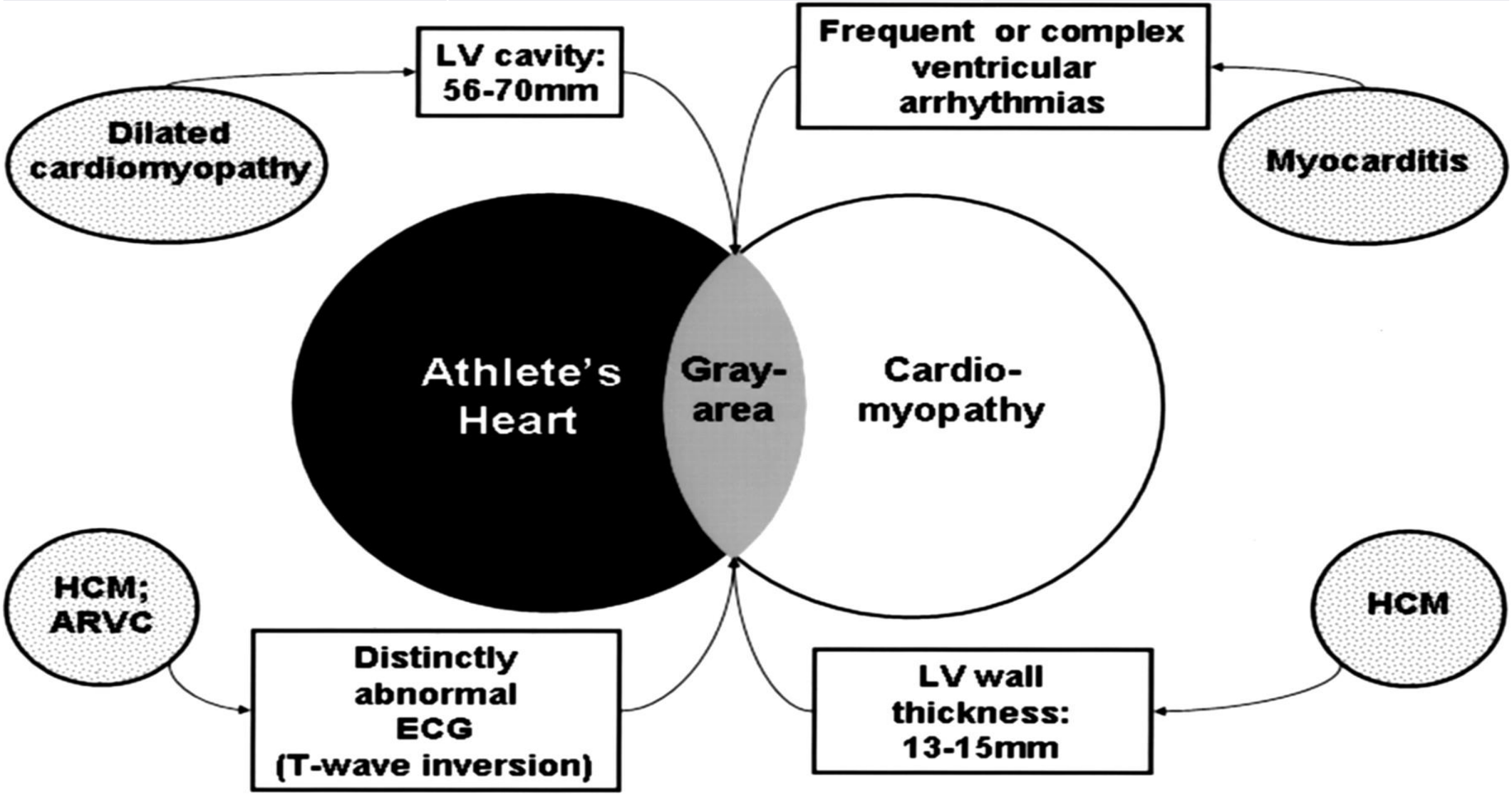
False-negative evaluations may result in devastating SCD

Difference between physiological ventricular hypertrophy of athletes and the pathological one (ventricular remodeling).

# Differences between physiological ventricular hypertrophy of the athlete and the pathological one (ventricular remodeling)

| | Physiological ventricular hypertrophy | Pathological ventricular hypertrophy ventricular remodeling |
|---|---|---|
| Location | Symmetrical, however, it may be asymmetrical. | Asymmetrical, however, it may be symmetrical. |
| Relative Ischemia | Absent. | Present. |
| Myocitic/Non-myocitic Component Relationship | Maintained. | Loss of balance in favor of the non-myocitic component (fibrosis). |
| Energetic Cycle | Aerobiosis. | Anaerobiosis. |
| Renin-angiotensin-aldosterone Mechanism | Normal. | Increased. |
| Norepinephrine | Normal. | Increased. |
| Atrial Natriuretic Peptide | Normal. | It may be increased. |
| Pump Function | Normal. | Depressed. |
| Heart Rate | Tendency to sinus bradyarrhythmia by vagotony. | Frequent tachycarrhythmia and sympathotony. |
| LV Pd2 | Normal. | Increased. |
| Pulmonary Artery Pressure And Central Venous Pressure | Normal. | It may be increased. |
| ANS | Parasympathetic predominance. | Sympathetic predominance. |

| | | |
|---|---|---|
| | Physiological ventricular hypertrophy | |
| Curve Of Dissociation of Hb | Deviation to the right. | Deviation to the left. |
| Echocardiogram | Proportional growth between the diameter and the thickness of walls.<br>Normal LA. | Loss of walls thickness/diameter ratio.<br>Increased LA. |



# Differential diagnosis of athlete heart vs hypertrophic cardiomyopathy (HCM)

| | Athlete's heart | HCM |
|---|---|---|
| LVH* | LVH mild (< 13 mm) and symmetrical or concentric | > 15 mm. Between 13 and 15mm "grey zone" Asymmetric. |
| Left ventricle end-diastolic diameter (LV-EDD) † | < 60 mm | > 70 mm |
| Diastolic function | Normal (E:A ratio > 1) | Abnormal (E:A ratio < 1) |
| Septal hypertrophy | Symmetric | Asymmetric (in HCM) |
| Family history | None | May be present |
| BP response to exercise | Normal | Normal or reduced systolic BP response. Eventually arrhythmias. |
| Deconditioning | LVH regression in ≈80% of cases | No LVH regression |
| Spatial QRS-T angle | < 45° | > 45° |
| T-wave inversion (TWI) from V1 to V4 with and without J-point elevation (**Calore 2015**) | J-point elevation and TWI confined to lead V1-V4 | ST-SE without J-point elevation preceding anterior TWI may reflect cardiomyopathy. |
| Leads with T-wave inversion (TWI) ( **Zaidi 2015**) | In anterior leads was associated with mild cardiac disease in 4.8% | In inferolateral leads revealed HCM and LVH in 60% of cases. |

*A value of 13 to 15 mm is indeterminate.
†A value of 60 to 70 mm is indeterminate.
E: A ratio = ratio of early to late atrial transmitral flow velocity.

# Differences between physiological ventricular hypertrophy of athletes and hypertrophic cardiomyopathy (HCM) when both present wall thickness between 13 mm & 15 mm

The concentric or symmetrical form of HCM (5%), may be confused with the athlete's heart with physiological hypertrophy of its walls, since the increase is not asymmetrical. For the differential diagnosis, the following criteria could be used:

| | Athlete | HCM |
|---|---|---|
| Female Gender | Negative | Positive |
| Decrease of hypertrophy(ventricular mass) with less physical training (Martin 1986) | Positive: Estimated left ventricular mass was 20% lower after 3 and 8 weeks of inactivity. | Negative |
| Family history or provable genetic mutation | Negative | Positive |
| Bizarre ECG pattern of LVH | No | Yes |
| LV cavity < 45 mm | No | Yes |
| LV cavity > 55 mm | Yes | No |
| LAE | No | Yes |

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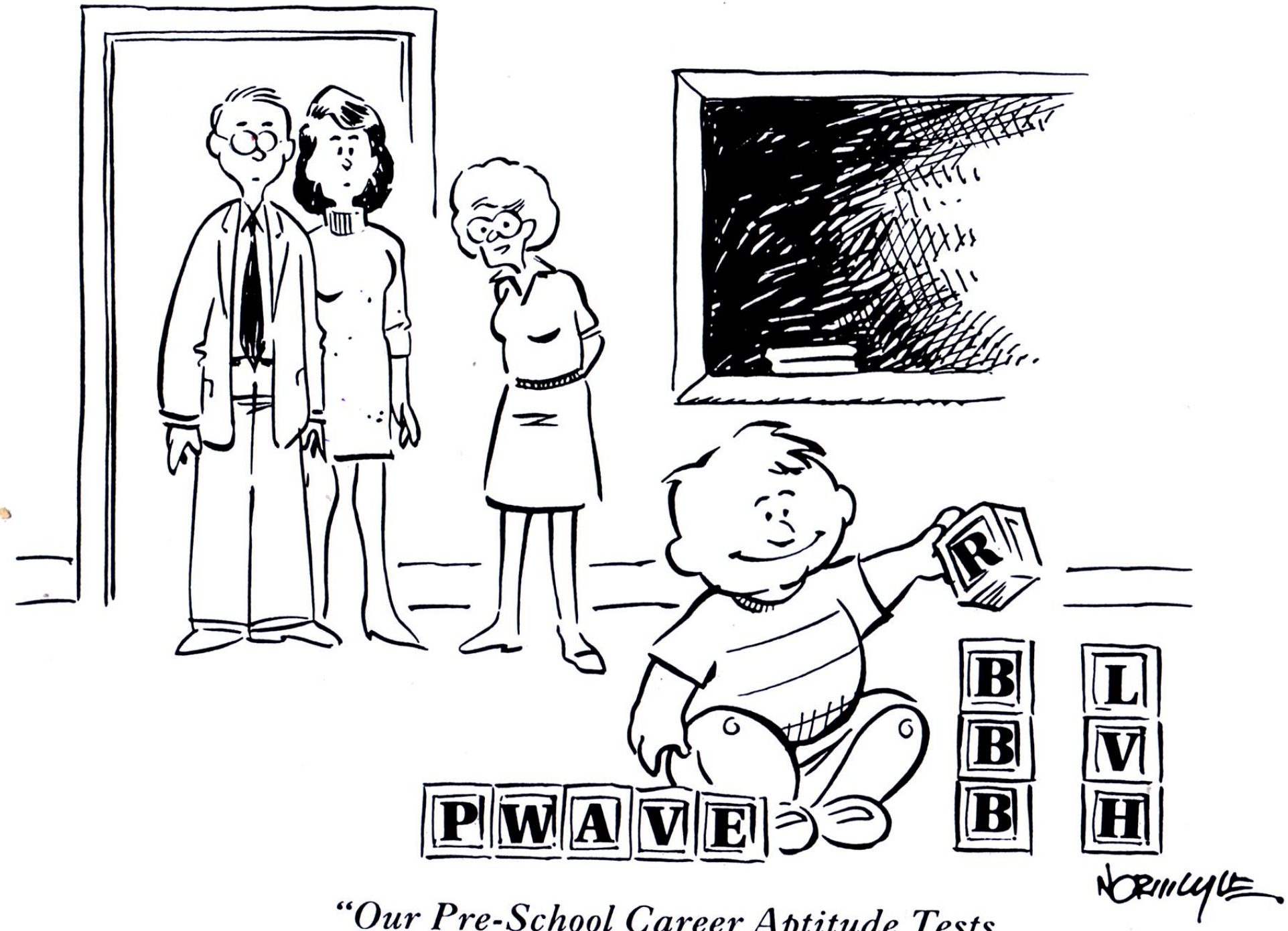


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