Sudden Cardiac Death in Sports: Causes and Current Screening Recommendations

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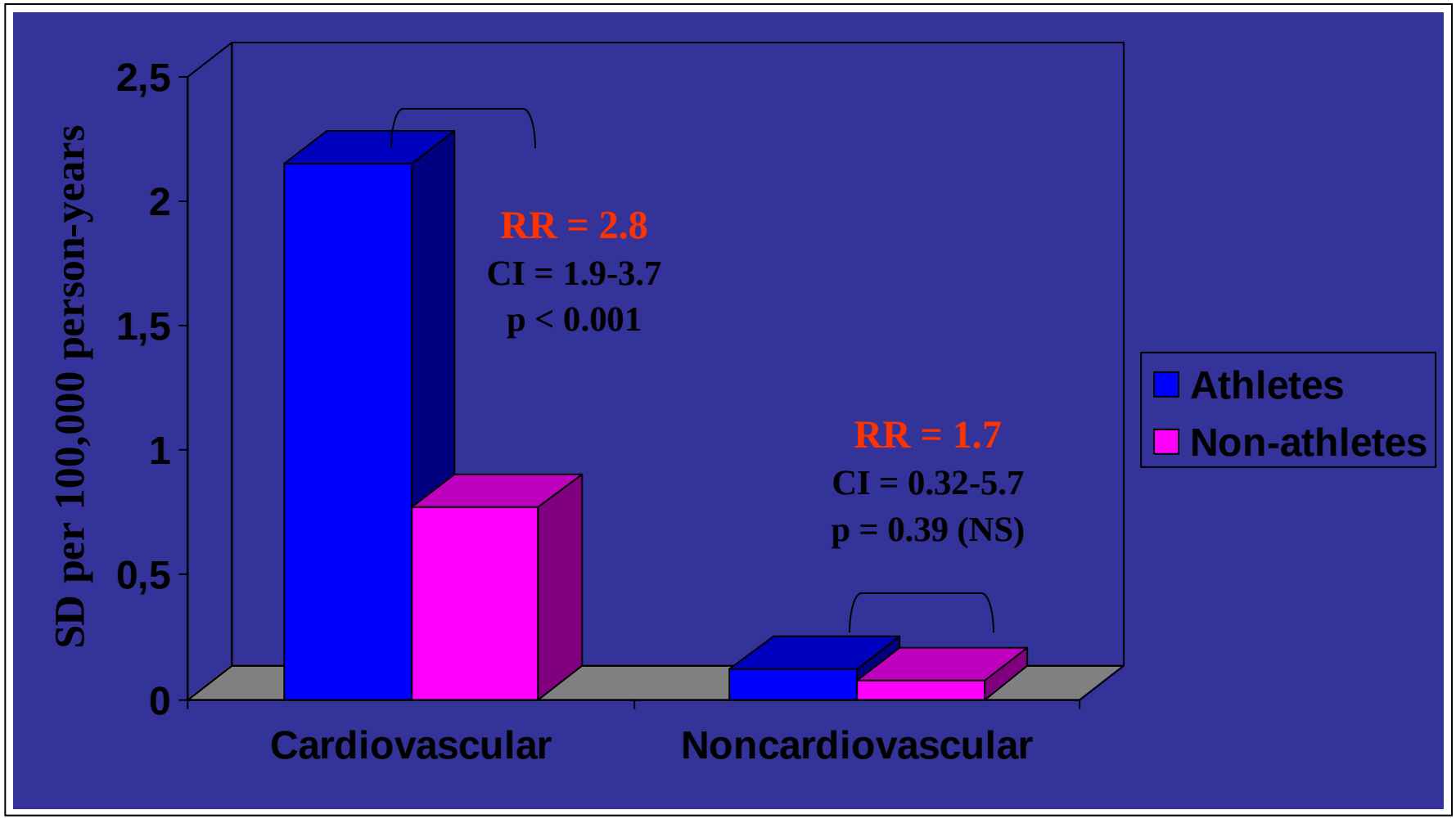
Athlete Subgroups

Age	Young Athletes (≤35 yrs)	Older athletes (>35 yrs)
Sports	A variety of sports (ball games)	Jogging and running
Level	Competitive activity	Leisure sports activity
Pathology	Large spectrum of cardiac disease (congenital and genetic)	Atherosclerotic coronary artery disease
Clinical history	Unsuspected heart disease (up to 75%)	Known coronary artery disease (up to 80%)

Relative risk of sport-related SD by cardiovascular and non-cardiovascular diseases in adolescents and young adults



Corrado et al. J Am Coll Cardiol 2003; 42:1959-63

Cardiovascular causes of sudden death associated with sports

Adults (age > 35 years):

Atherosclerotic coronary artery disease

Young competitive athletes (age ≤35 years):

Hypertrophic cardiomyopathy

Arrhythmogenic right ventricular cardiomyopathy

Congenital anomalies of coronary arteries

Myocarditis

Aortic rupture

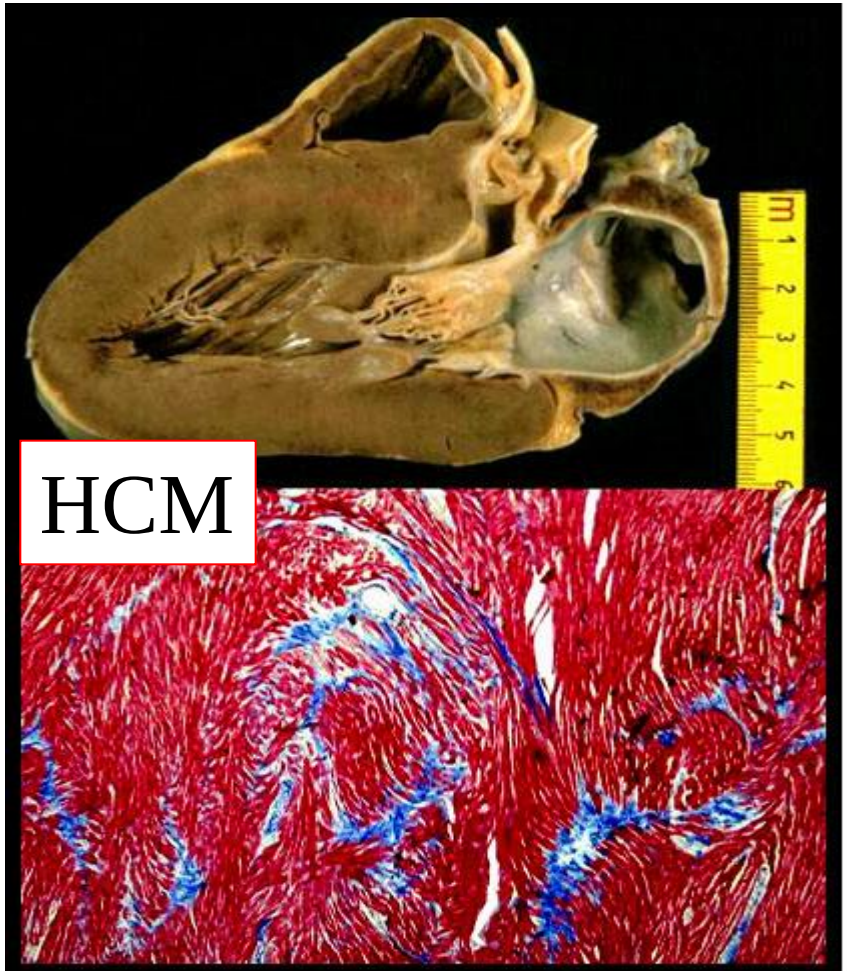
Valvular disease

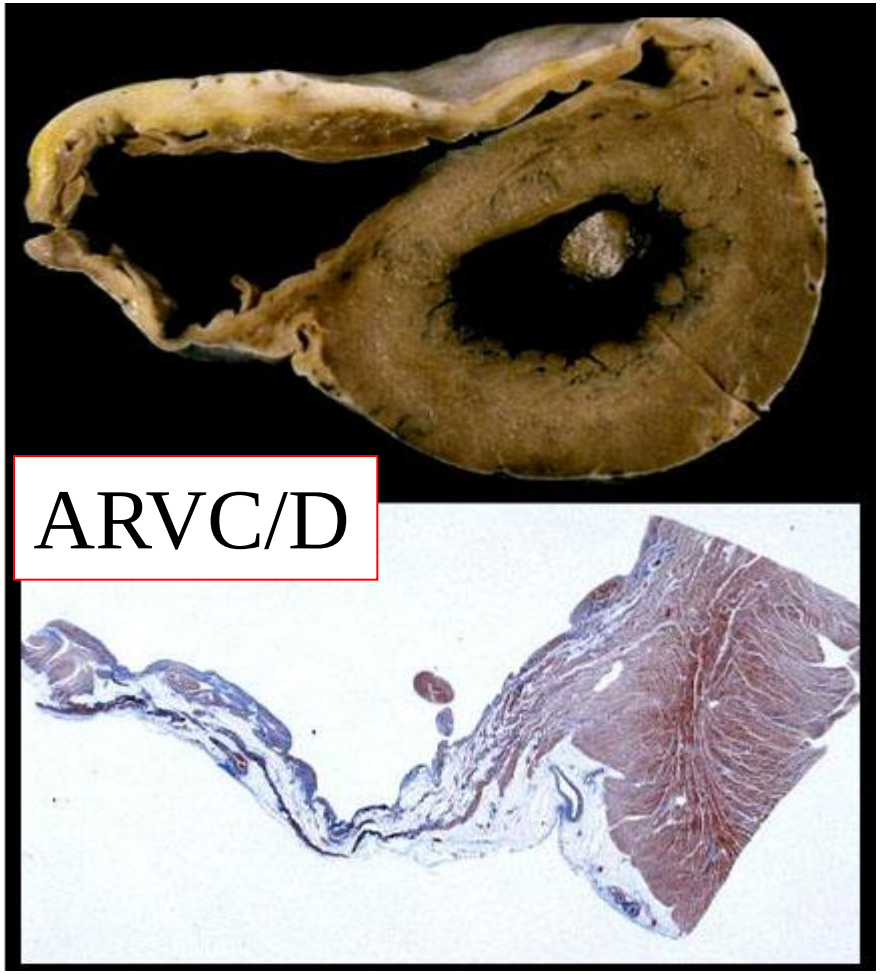
Preexcitation syndromes and conduction diseases

Ion channel diseases

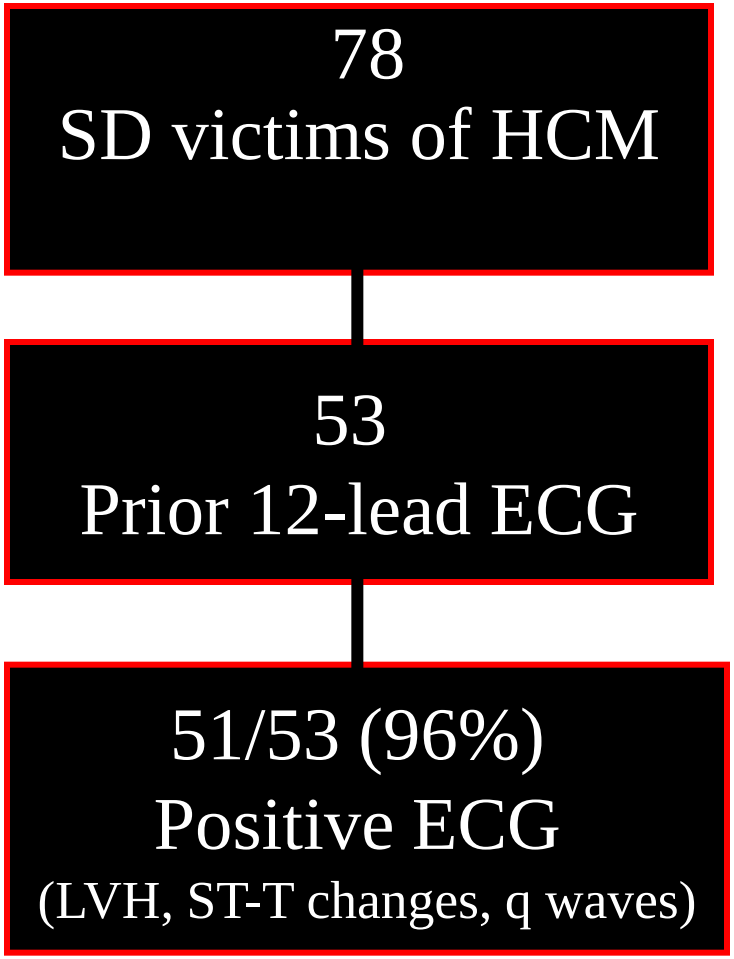
Congenital heart disease, operated or unoperated

Leading causes of sudden cardiovascular death in young competitive athletes



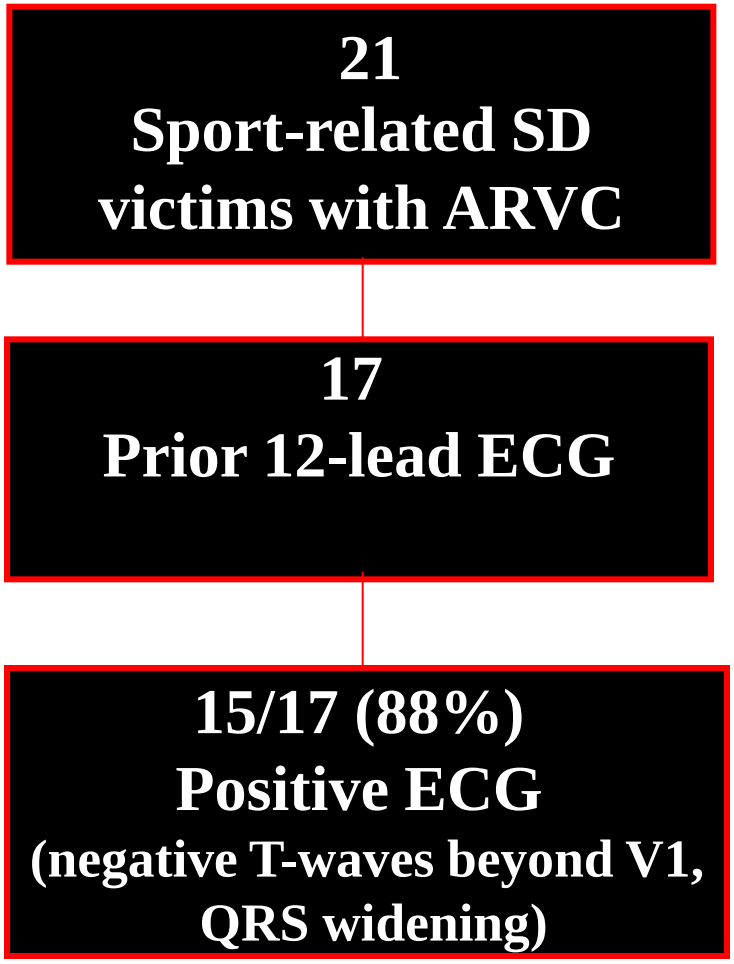


Sensitivity of 12-lead ECG in SD victims of HCM



Maron et al. Circulation 1982; 65: 1388-94

Sensitivity of 12-lead ECG in sport-related SD victims with ARVC



Corrado et al PACE 2002; 25 (abstr) :544

Table 4 ECG Features of cardiac diseases detectable at pre-participation screening in young competitive athletes

Disease	QTc interval	P wave	PR interval	QRS complex	ST interval	T wave	Arrhythmias
HCM	Normal	(left atrial enlargement)	Normal	Increased voltages in mid-left precordial leads; abnormal Q waves in inferior and/or lateral leads; (LAD, LBBB); (delta wave)	Down-sloping (up-sloping)	Inverted in mid-left precordial leads; (giant and negative in the apical variant)	(Atrial fibrillation); (PVB); (VT)
Arrhythmogenic right ventricular cardiomyopathy/ dysplasia	Normal	Normal	Normal	Prolonged >110 ms in right precordial leads; epsilon wave in right precordial leads; reduced voltages ≤0.5 mV in frontal leads; (RBBB)	(Up-sloping in right precordial leads)	Inverted in right precordial leads	PVB with a LBBB pattern; (VT with a LBBB pattern)
Dilated cardiomyopathy	Normal	(Left atrial enlargement)	(Prolonged ≥0.21 s)	LBBB	Down-sloping (up-sloping)	Inverted in inferior and/or lateral leads	PVB; (VT)
Long QT syndrome	Prolonged >440 ms in males >460 ms in females	Normal	Normal	Normal	Normal	Bifid or biphasic in all leads	(PVB); (torsade de pointes)
Brugada syndrome	Normal		Prolonged ≥0.21 s	S1S2S3 pattern; (RBBB/LAD)	Up-sloping coved-type in right precordial leads	Inverted in right precordial leads	(Polymorphic VT); (atrial fibrillation) (sinus bradycardia)
Lenègre disease	Normal	Normal	Prolonged ≥0.21 s	RBBB; RBBB/LAD; LBBB	Normal	Secondary changes	(2nd or 3rd degree AV block)
Short QT syndrome	Shortened <300 ms	Normal	Normal	Normal	Normal	Normal	Atrial fibrillation (polymorphic VT);
Pre-excitation syndrome (WPW)	Normal	Normal	Shortened <0.12 s	Delta wave	Secondary changes	Secondary changes	Supraventricular tachycardia; (atrial fibrillation)
Coronary artery diseases[a]	(Prolonged)	Normal	Normal	(Abnormal Q waves)[b]	(Down- or up-sloping)	Inverted in ≥2 leads	PVB; (VT);

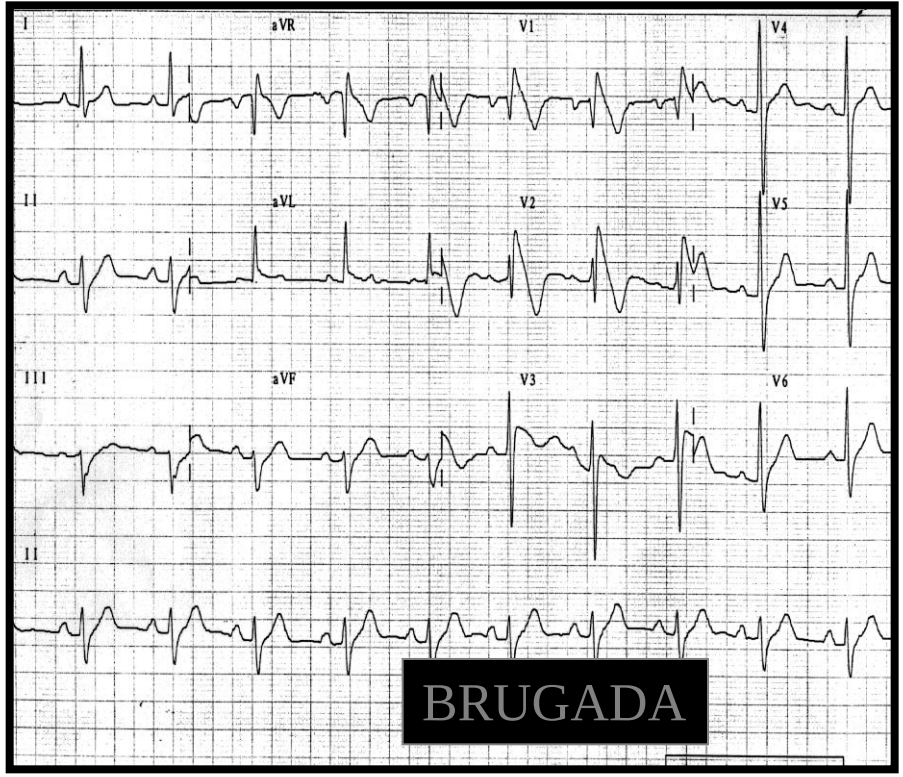
Less common or uncommon ECG findings are reported in brackets.

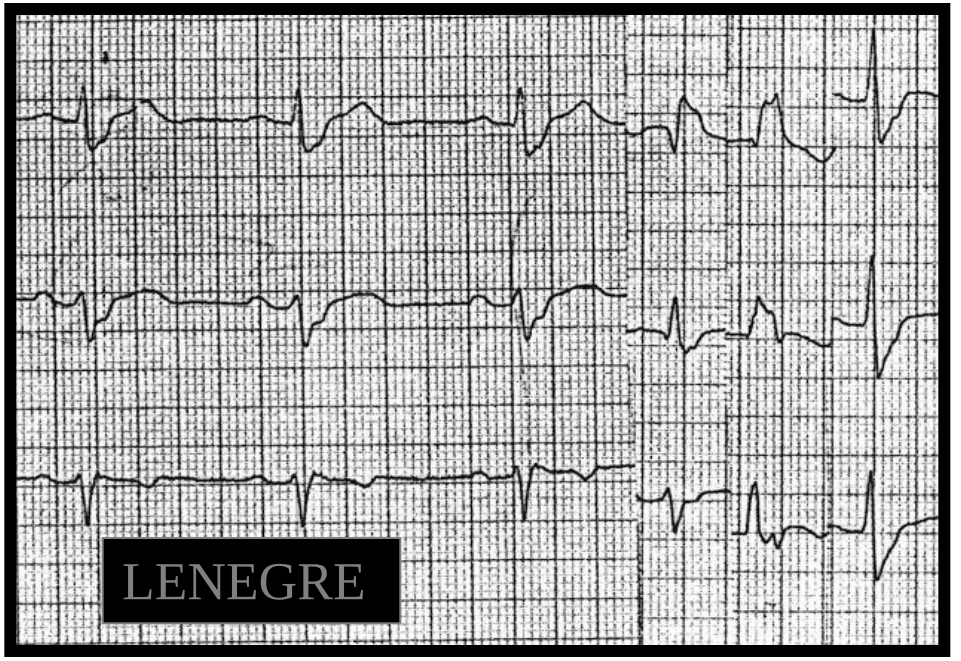
QTc: QT interval corrected for heart rate by Bazett's formula. LBBB: left bundle branch block. RBBB: right bundle branch block. LAD: left axis deviation of −30° or more. PVB: either single or coupled premature ventricular beats. VT: either non-sustained or sustained ventricular tachycardia.

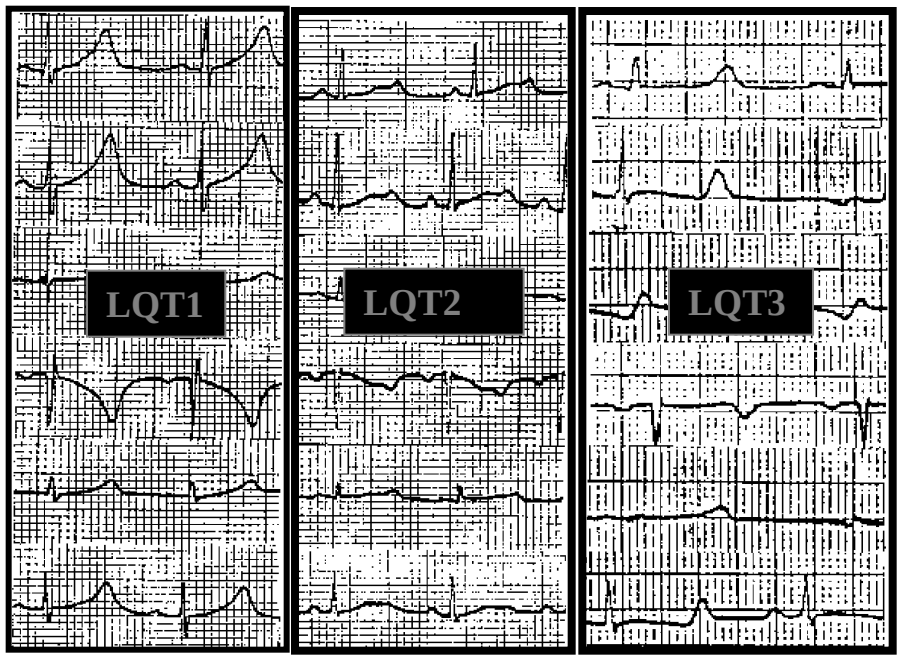
[a]Coronary artery diseases: either premature coronary atherosclerosis or congenital coronary anomalies.

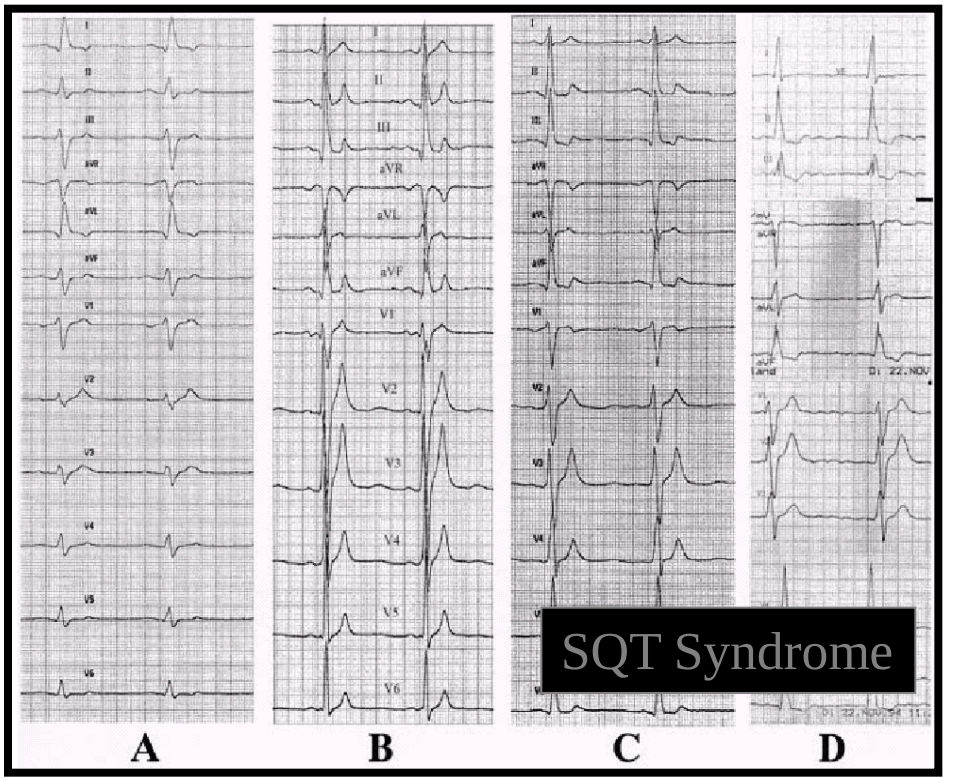
[b]Abnormal Q waves (see Table 3).

Corrado et al. Eur Heart J 2005


I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6
II
BRUGADA


LENEGRE


LQT1
LQT2
LQT3


SQT Syndrome
A
B
C
D

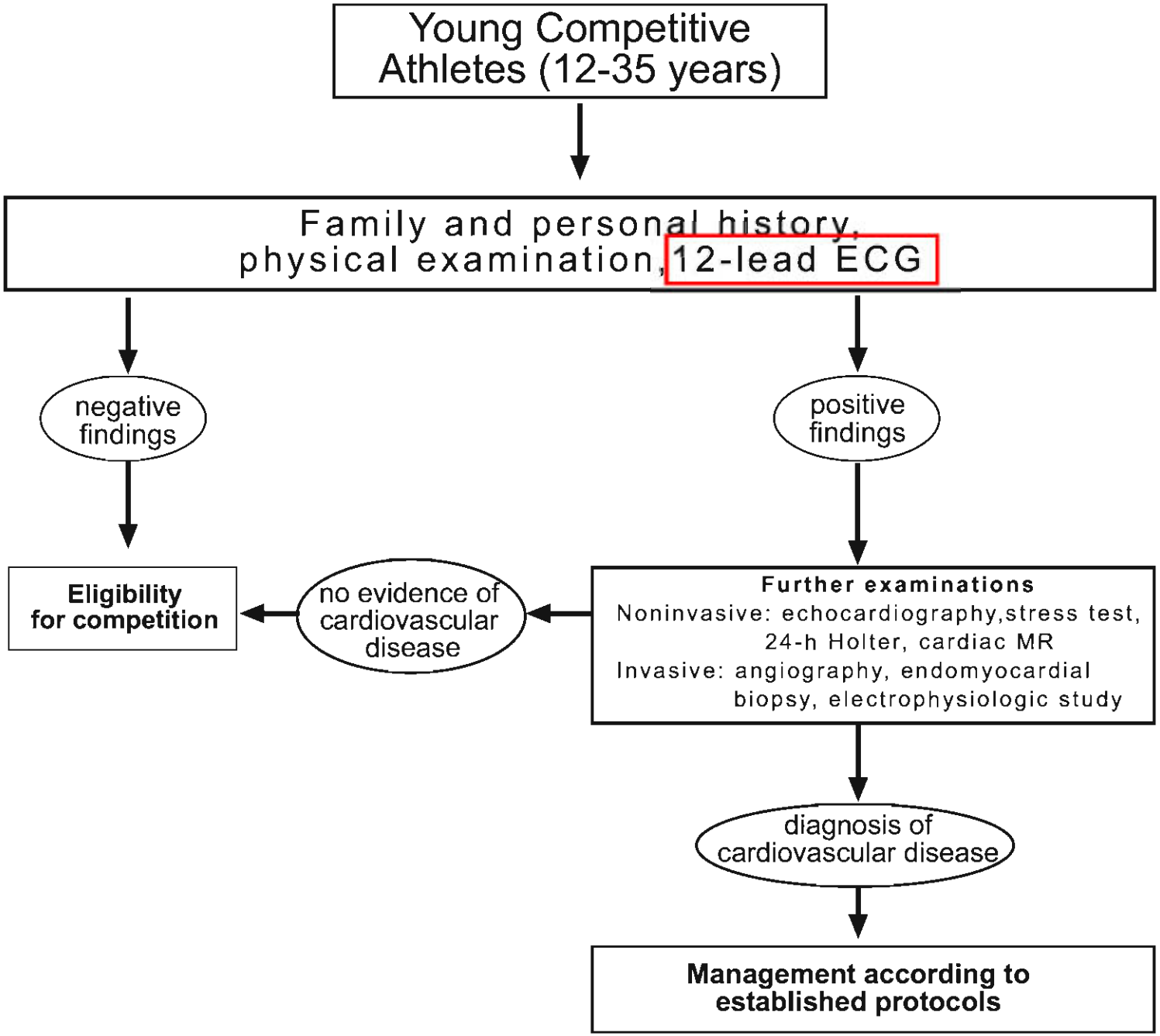
European Heart Journal (2005) 26, 516–524
doi:10.1093/eurheartj/ehi108

ESC Report

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

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

Domenico Corrado[1*], Antonio Pelliccia[2], Hans Halvor Bjørnstad[3], Luc Vanhees[4], Alessandro Biffi[2], Mats Borjesson[5], Nicole Panhuyzen-Goedkoop[6], Asterios Deligiannis[7], Erik Solberg[8], Dorian Dugmore[9], Klaus P. Mellwig[10], Deodato Assanelli[11], Pietro Delise[12], Frank van-Buuren[10], Aris Anastasakis[13], Hein Heidbuchel[4], Ellen Hoffmann[14], Robert Fagard[4], Silvia G. Priori[15], Cristina Basso[19], Eloisa Arbustini[16], Carina Blomstrom-Lundqvist[17], William J. McKenna[18], and Gaetano Thiene[19]


Young Competitive Athletes (12-35 years)
Family and personal history, physical examination, 12-lead ECG
negative findings
positive findings
Eligibility for competition
no evidence of cardiovascular disease
Further examinations
Noninvasive: echocardiography,stress test, 24-h Holter, cardiac MR
Invasive: angiography, endomyocardial biopsy, electrophysiologic study
diagnosis of cardiovascular disease
Management according to established protocols

The New England Journal of Medicine

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SCREENING FOR HYPERTROPHIC CARDIOMYOPATHY IN YOUNG ATHLETES

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ABSTRACT

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

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

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

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

Preparticipation Athletic Screening (Padua:1979-1996)

- Athletes screened: 33,735
- Athletes disqualified: 1,058 (3%)
- Cardiovascular causes of disqualification: 621 (59%)
- Hypertrophic Cardiomyopathy: 22 (0.07% of 33,735)

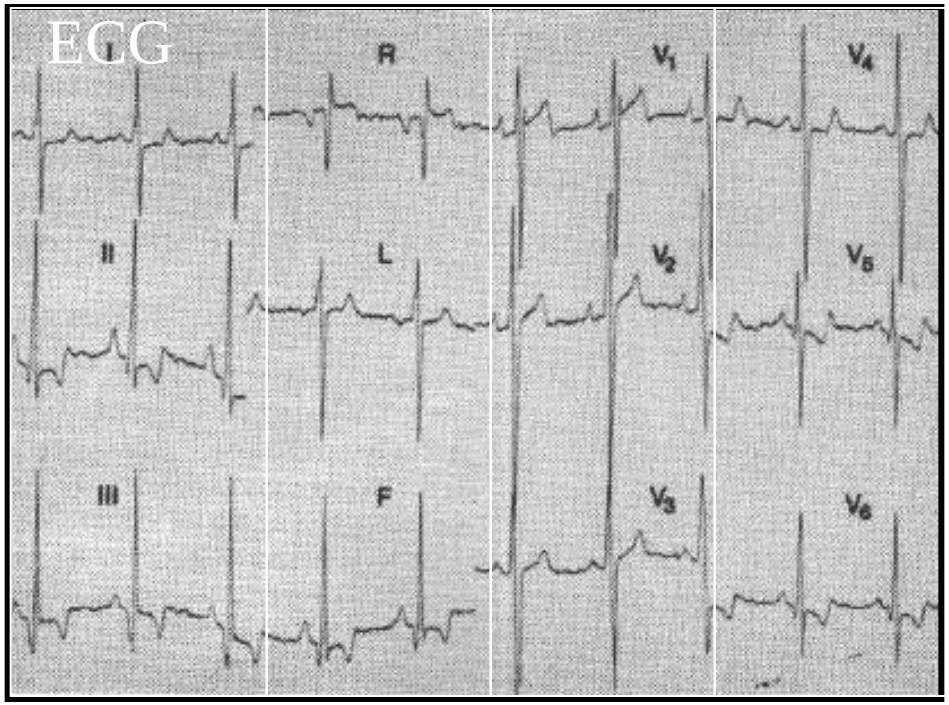
Corrado et al. N Engl J Med 1998; 339: 364-9

Clinical Characteristics of Athletes Disqualified for HCM (Padua:1979-1996)

N.:	22
Age:	20±4 yrs
Sex (% male):	90
Reason for echo: (80%)	ECG changes
LV wall Thickness:	19±3 mm
LV cavity:	43±2 mm
LVH after detraining:	unchanged

Corrado et al N Engl J Med 1998; 339: 364-369

Prevalence of HCM in young white people



ECG: **0.07%** (22 of 33,735)

Corrado et al NEJM, 1998

ECHO: **0.10%** (2 of 2,030)

Maron et al Circulation, 1995

Prevalence of Cardiomyopathy in Italian Asymptomatic Children With Electrocardiographic T-Wave Inversion at Preparticipation Screening

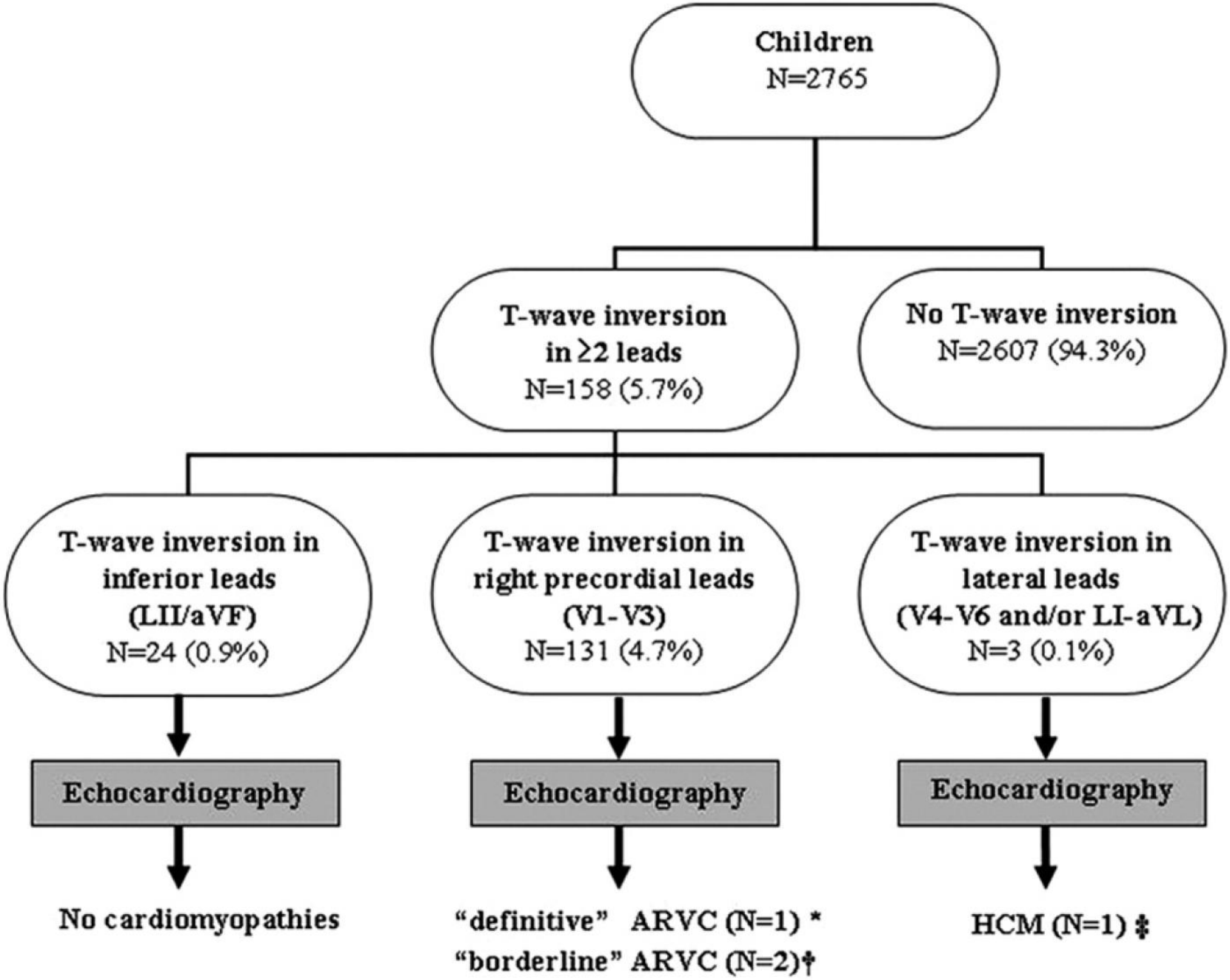
Federico Migliore, MD; Alessandro Zorzi, MD; Pierantonio Michieli, MD, PhD; Martina Perazzolo Marra, MD, PhD; Mariachiara Siciliano, MD; Ilaria Rigato, MD, PhD; Barbara Bauce, MD, PhD; Cristina Basso, MD, PhD; Daniela Toazza, MD; Maurizio Schiavon, MD; Sabino Iliceto, MD; Gaetano Thiene, MD; Domenico Corrado, MD, PhD

Background—T-wave inversion on a 12-lead ECG is usually dismissed in young people as normal persistence of the juvenile pattern of repolarization. However, T-wave inversion is a common ECG abnormality of cardiomyopathies such as hypertrophic cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy, which are leading causes of sudden cardiac death in athletes. We prospectively assessed the prevalence, age relation, and underlying cardiomyopathy of T-wave inversion in children undergoing preparticipation screening.

Methods and Results—The study population included 2765 consecutive Italian children (1914 male participants; mean age, 13.9±2.2 years; range 8–18 years) undergoing preparticipation screening including an ECG. Of 229 children (8%) who underwent further evaluation because of positive findings at initial preparticipation screening, 33 (1.2%) were diagnosed with cardiovascular disease. T-wave inversion was recorded in 158 children (5.7%) and was localized in the right precordial leads in 131 (4.7%). The prevalence of right precordial T-wave inversion decreased significantly with increasing age (8.4% in children <14 years of age versus 1.7% in those ≥14 years; $P<0.001$), pubertal development (9.5% of children with incomplete versus 1.6% with complete development; $P<0.001$), and body mass index below the 10th percentile ($P<0.001$). Incomplete pubertal development was the only independent predictor for right precordial T-wave inversion (odds ratio, 3.6; 95% confidence interval, 1.9–6.8; $P<0.001$). Of 158 children with T-wave inversion, 4 (2.5%) had a diagnosis of cardiomyopathy, including arrhythmogenic right ventricular cardiomyopathy (n=3) and hypertrophic cardiomyopathy (n=1).

Conclusions—The prevalence of T-wave inversion decreases significantly after puberty. Echocardiographic investigation of children with postpubertal persistence of T-wave inversion at preparticipation screening is warranted because it may lead to presymptomatic diagnosis of a cardiomyopathy that could lead to sudden cardiac death during sports. (***Circulation*. 2012;125:529-538.**)

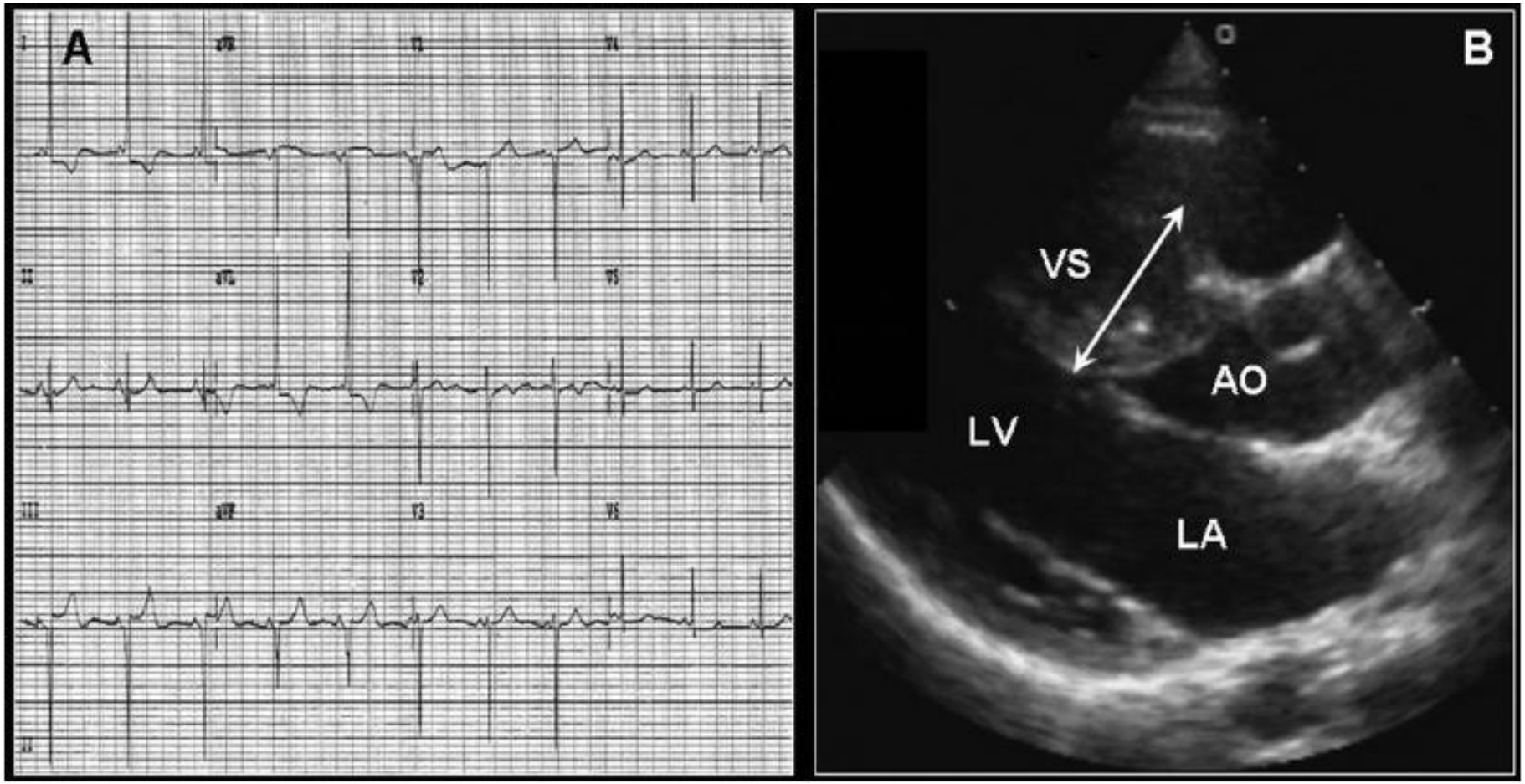
Key Words: arrhythmogenic right ventricular dysplasia ■ athletes ■ cardiomyopathy, hypertrophic ■ child ■ electrocardiography



Migliore F…Corrado D, Circulation 2012:125:529-538

ECG and echocardiographic findings in a 14-year-old male

ECG and echocardiographic findings in a 15-year-old male



Trends in Sudden Cardiovascular Death in Young Competitive Athletes After Implementation of a Preparticipation Screening Program

Domenico Corrado, MD, PhD
Cristina Basso, MD, PhD
Andrea Pavei, MD
Pierantonio Michieli, MD, PhD
Maurizio Schiavon, MD
Gaetano Thiene, MD

Context A nationwide systematic preparticipation athletic screening was introduced in Italy in 1982. The impact of such a program on prevention of sudden cardiovascular death in the athlete remains to be determined.

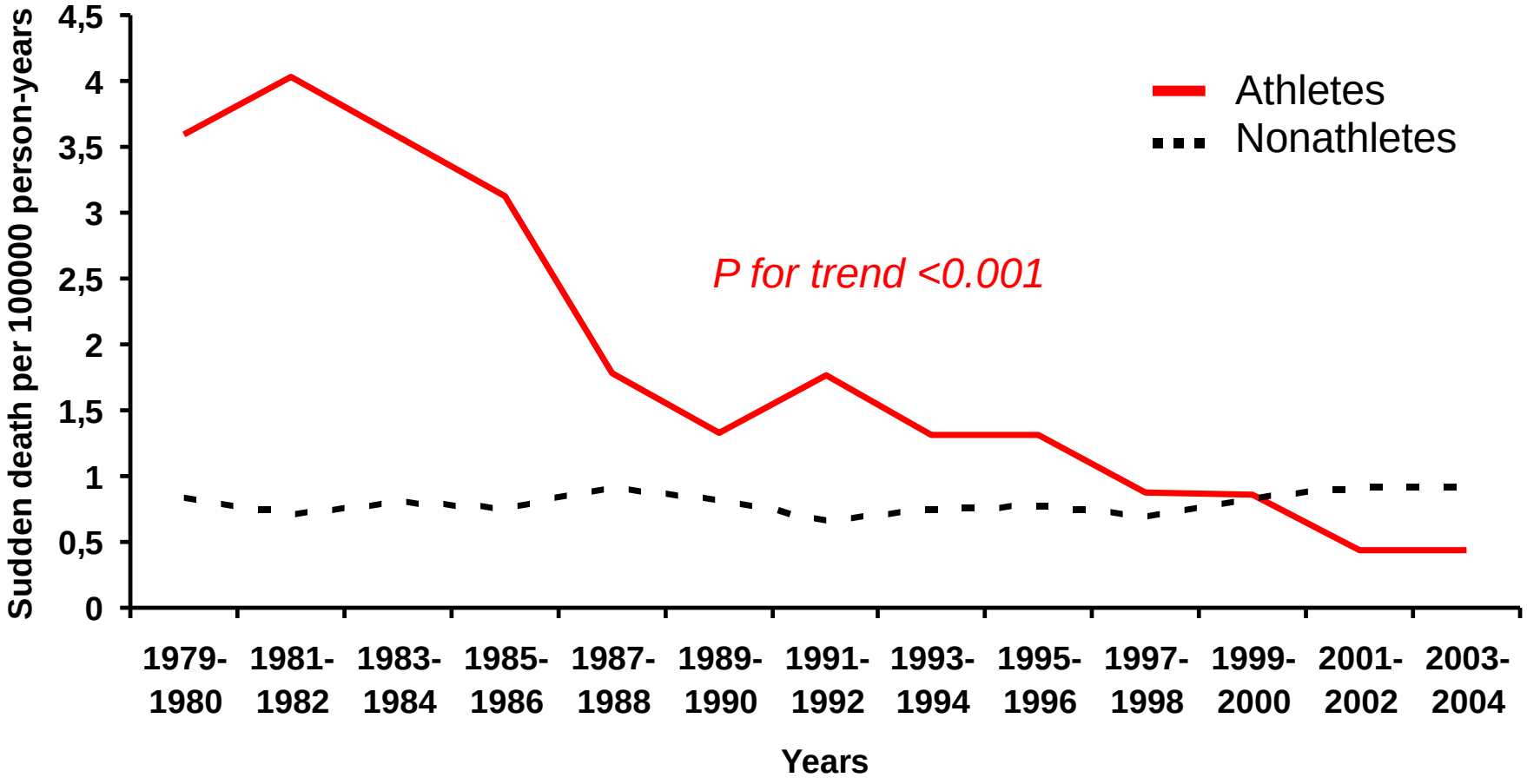
Objective To analyze trends in incidence rates and cardiovascular causes of sudden death in young competitive athletes in relation to preparticipation screening.

Design, Setting, and Participants A population-based study of trends in sudden cardiovascular death in athletic and nonathletic populations aged 12 to 35 years in the Veneto region of Italy between 1979 and 2004. A parallel study examined trends in cardiovascular causes of disqualification from competitive sports in 42 386 athletes undergoing preparticipation screening at the Center for Sports Medicine in Padua (22 312 in the early screening period [1982-1992] and 20 074 in the late screening period [1993-2004]).

THE MAJORITY OF YOUNG ATHletes who die suddenly have previously unsuspected structural heart disease.[1-8] Cardi-

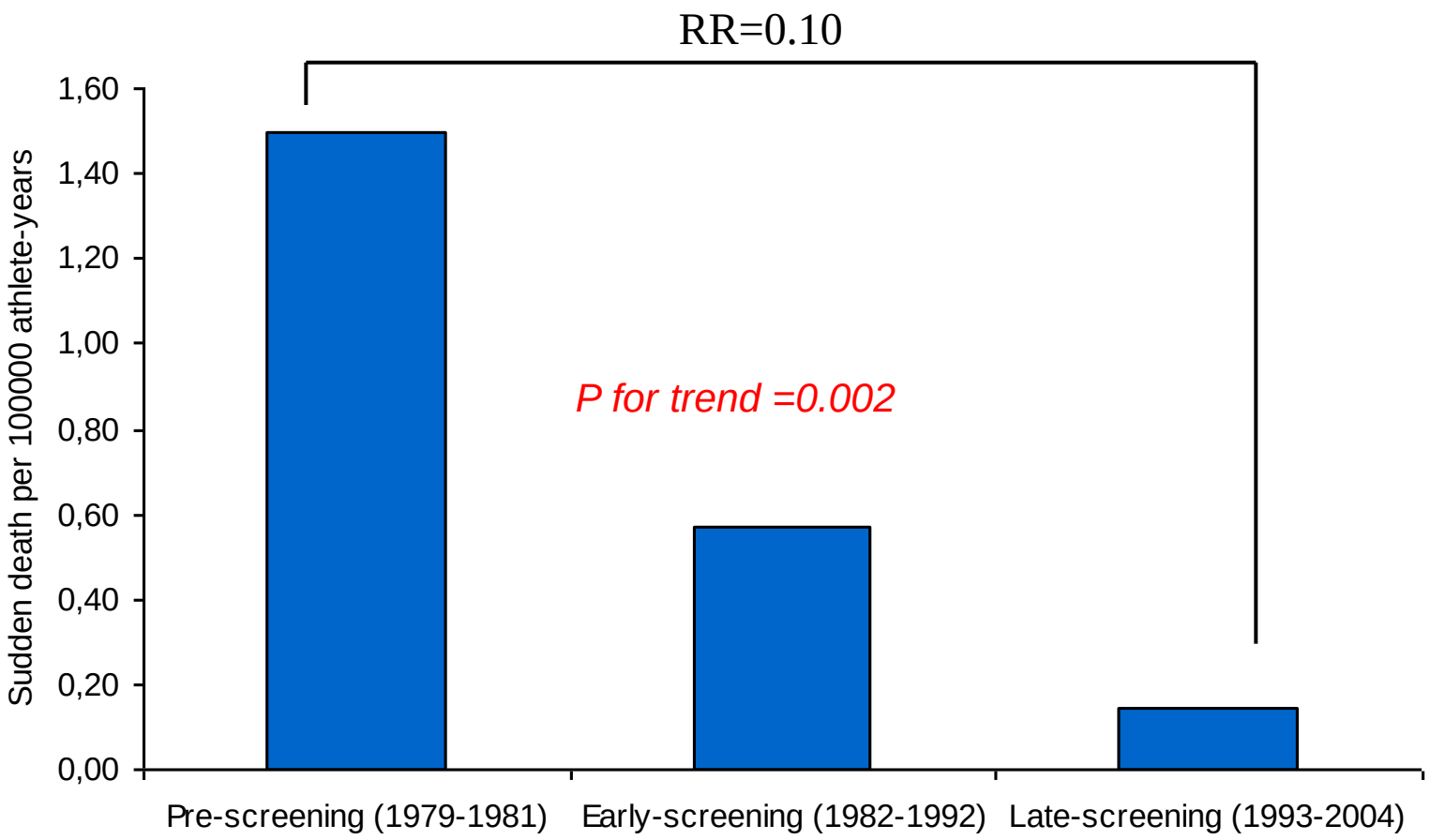
Corrado et al JAMA 2006;296:1593-1601

Annual Incidence Rates of Sudden Cardiovascular Death in Screened Competitive Athletes and Unscreened Nonathletes Aged 12 to 35 Years in the Veneto Region of Italy (1979-2004)



Corrado et al JAMA 2006;296:1593-1601

Mortality trend for sudden death from Cardiomyopathies



Corrado et al JAMA 2006;296:1593-1601

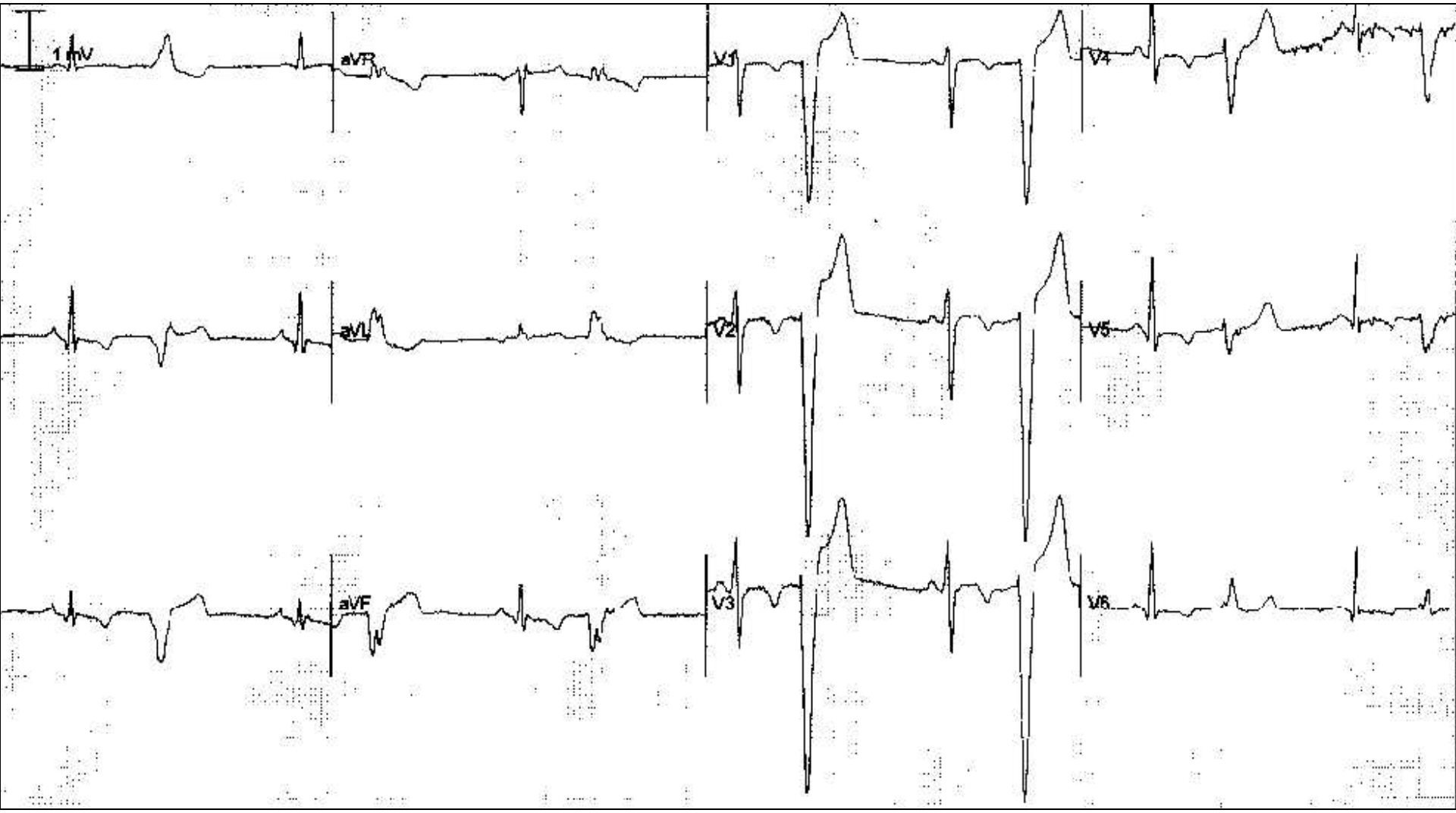
Cardiovascular conditions causing disqualification from competitive sports in 879 athletes over 2 consecutive screening periods (1982-1992 and 1993-2004) at the Center for Sports Medicine in Padua, Italy

	NUMBER OF DISQUALIFIED ATHETES*			
CARDIOVASCULAR CAUSES OF DISQUALIFICATION	***Total Study Period (1982-2004) N=879 (%)***	***Early screening Period (1982-1992) N=455 (%)***	***Late screening Period (1993-2004) N=424 (%)***	**P-value**
Rhythm and conduction abnormalities	345 (39)	166 (36)	179 (42.2)	0.13
- ventricular arrhythmias	173 (19.6)	81 (18)	92 (21.6)	0.20
- supraventricular arrhythmias	73 (8.3)	39 (8.6)	34 (8.0)	0.56
- WPW Syndrome	55 (6.3)	29 (6.3)	26 (6.1)	0.88
- LBBB or RBBB & LAD	26 (3.0)	8 (1.7)	18 (4.2)	0.10
- second Degree AV Block	13 (1.5)	7 (1.5)	6 (1.4)	0.89
- long QT Syndrome	5 (0.6)	2 (0.4)	3 (0.7)	0.93
Systemic hypertension:	205 (23)	118 (25.9)	87 (20.5)	0.96
Valvular disease (including MVP):	184 (21)	106 (23.3)	78 (18.4)	0.09
Cardiomyopathies	**60 (6.8)**	**20 (4.4)**	**40 (9.4)**	**0.005**
- hypertrophic	**30 (3.4)**	**14 (3.0)**	**16 (3.8)**	**0.50**
- arrhythmogenic right ventricular	**16 (1.8)**	**2 (0.4)**	**14 (3.3)**	**0.004**
- dilated	**14 (1.6)**	**4 (0.9)**	**10 (2.4)**	**0.21**
Coronary artery disease	11 (1.3)	2 (0.4)	9 (2.1)	0.05
Other	74 (8.4)	43 (9.5)	31 (7.3)	0.42

Case report

- 23 years-old male competitive athlete (soccer)
- Preparticipation cardiovascular screening:
  - Asymptomatic
  - Unremarkable family history
  - Normal physical examination
- Normal laboratory exams
- ECG

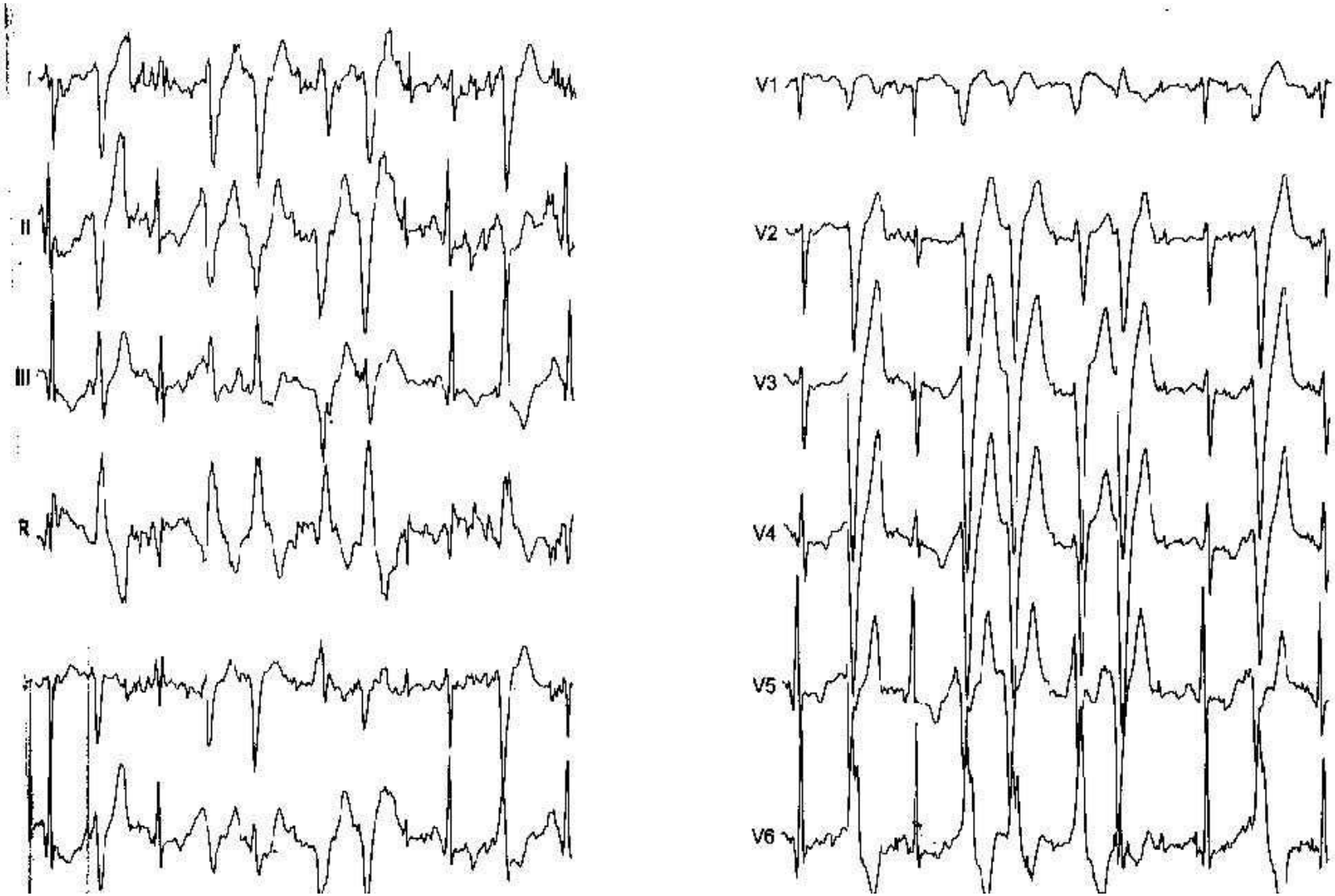
12-lead ECG



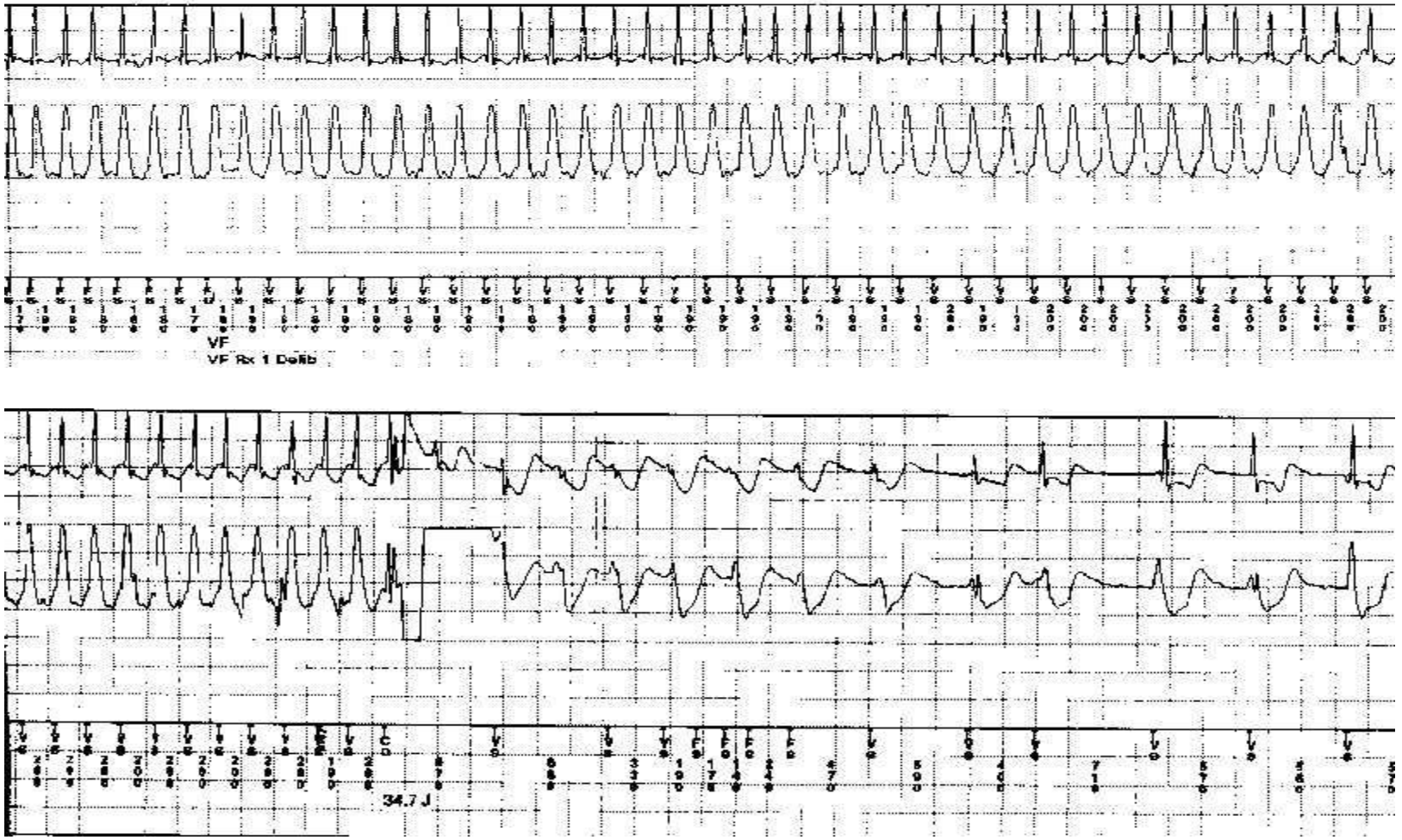
Contrast-enhanced Cardiac MR

24-hour Holter monitoring

(including training)

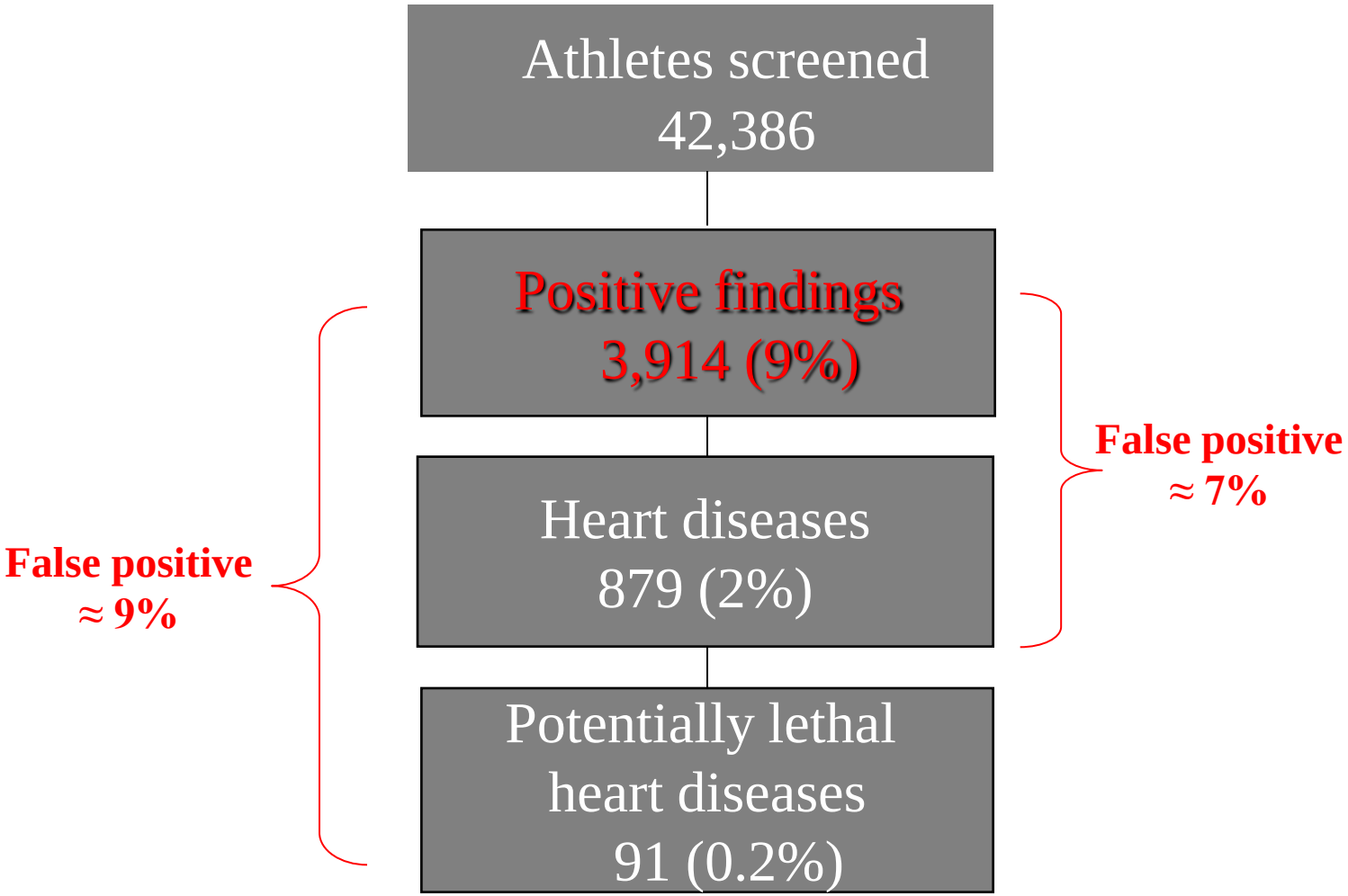


6 months later…



Screening of young athletes for Cardiovascular diseases

(Center for Sports Medicine, Padua 1979-2004)



Corrado et al JAMA 2006; 296: 1593-1601

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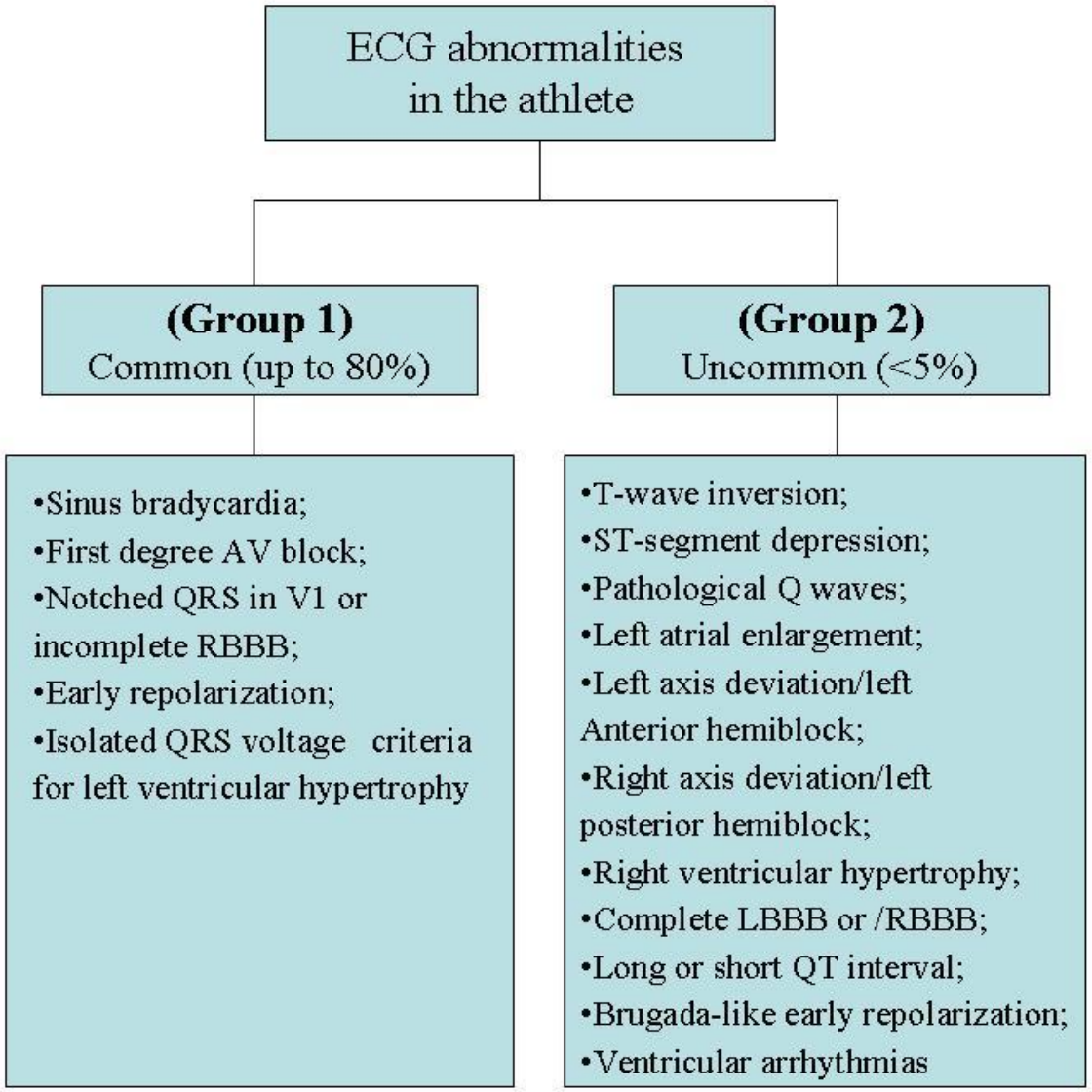
ESC REPORT

Recommendations for interpretation of 12-lead electrocardiogram in the athlete

Domenico Corrado[1]*, Antonio Pelliccia[2], Hein Heidbuchel[3], Sanjay Sharma[4], Mark Link[5], Cristina Basso[6], Alessandro Biffi[2], Gianfranco Buja[1], Pietro Delise[7], Ihor Gussac[8], Aris Anastasakis[9], Mats Borjesson[10], Hans Halvor Bjørnstad[11], François Carrè[12], Asterios Deligiannis[13], Dorian Dugmore[14], Robert Fagard[3], Jan Hoogsteen[15], Klaus P. Mellwig[16], Nicole Panhuyzen-Goedkoop[17], Erik Solberg[18], Luc Vanhees[3], Jonathan Drezner[19], N.A. Mark Estes, III[5], Sabino Iliceto[1], Barry J. Maron[20], Roberto Peidro[21], Peter J. Schwartz[22], Ricardo Stein[23], Gaetano Thiene[6], Paolo Zeppilli[24], and William J. McKenna[25] On behalf of the Sections of Sports Cardiology of the European Association of Cardiovascular Prevention and Rehabilitation; and the Working Group of Myocardial and Pericardial Disease of the European Society of Cardiology

Appropriate interpretation of the athlete's electrocardiogram saves lives as well as money



Corrado D, McKenna WJ: Eur Heart J 2007 ;28:1920-2

National health system

- In Italy screening is made feasible because of its limited costs in the setting of a mass-program.
- National health system developed in terms of health care and prevention services
- Infrastructure
- Sports physicians

How much is an athlete's life?

Atheletes screened	**1,000,000**
Estimate cost to initially screen all athletes (30∈)	**∈ 30,000,000**
Estimate cost to evaluate ~100,000 athletes with positive findings (60∈)	**∈ 6,000,000**
Total cost to of screening	**∈ 36,000,000**
N° of SDs in unscreened athletes (mortality 4/100000 athlete-years)	**40**
N° of SDs in screened athletes (mortality 0.4/100000 athlete-years)	**4**
Lives saved	**36**
Cost for a life saved	**∈ 1,000,000**
Cost for one year of life saved (YLS): 10 additional years of life	**∈ 100,000/YLS**
Cost for one year of life saved: 20 additional years of life	**∈ 50,000/YLS**
Cost for one year of life saved: 30 additional years of life	**∈ 33,000/YLS**

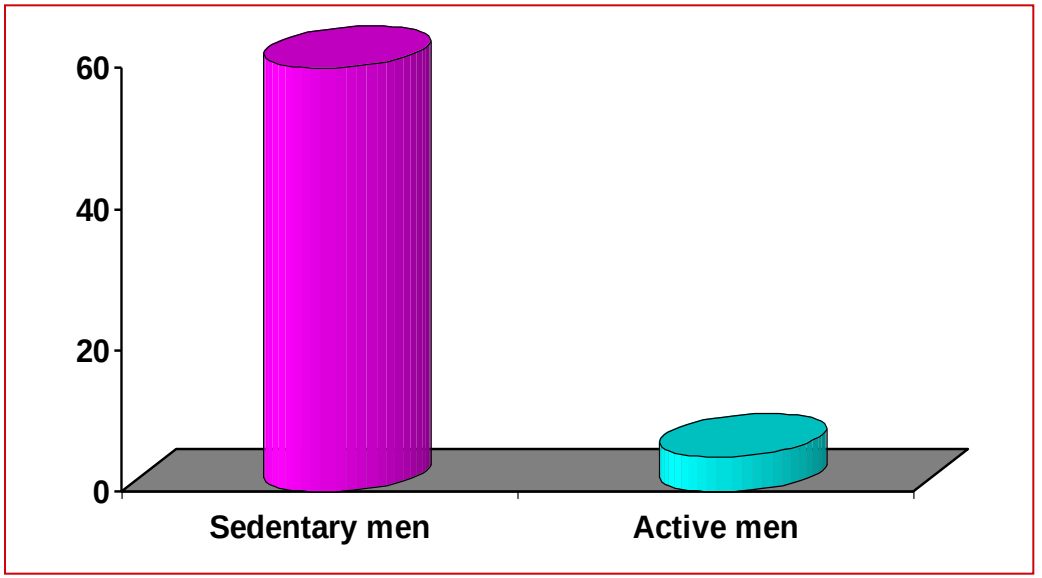
Athlete Subgroups

Age	Young Athletes (≤35 yrs)	Older athletes (>35 yrs)
Sports	A variety of sports (ball games)	Jogging and running
Level	Competitive activity	Leisure sports activity
Pathology	Large spectrum of cardiac disease (congenital and genetic)	Atherosclerotic coronary artery disease
Clinical history	Unsuspected heart disease (up to 75%)	Known coronary artery disease (up to 80%)

Exercise-related sudden death in middle aged/senior leisure time athletes

- Habitual sport activity in middle aged and older population offers protection over the long- term from the overall risk of myocardial infarction and sudden death

Relative Risk of Sudden Cardiac Death During Exercise*



Siscovick DS. NEJM 1984;311:874

- Physical exercise may acutely trigger sudden cardiac arrest mostly in persons who did not exercise regularly.

Incidence of SCD during Marathon

Author	Events	Study population	Study period	SCD rate
BJ Maron (JACC,1998)	Marine Corps(WA) Twin Cities (MN) Marathons	215,413 Marathon runners	30 years (1976 -1994)	0.5/100 000
DT Pedoe (2004)	London (UK) Marathon	539,312 Marathon runners	20 years (1981-2003)	1.5/100 000
DA Redelmeier (BMJ 2007)	26 (USA) Marathons	3,292,268 Marathon runners	30 years (1975-2004)	0.8/100 000
Kim JH (NEJM 2012)	USA Marathon & half-Maraton	10.900.000 Marathon runners	10 years (2000-2010)	0.5/100 000

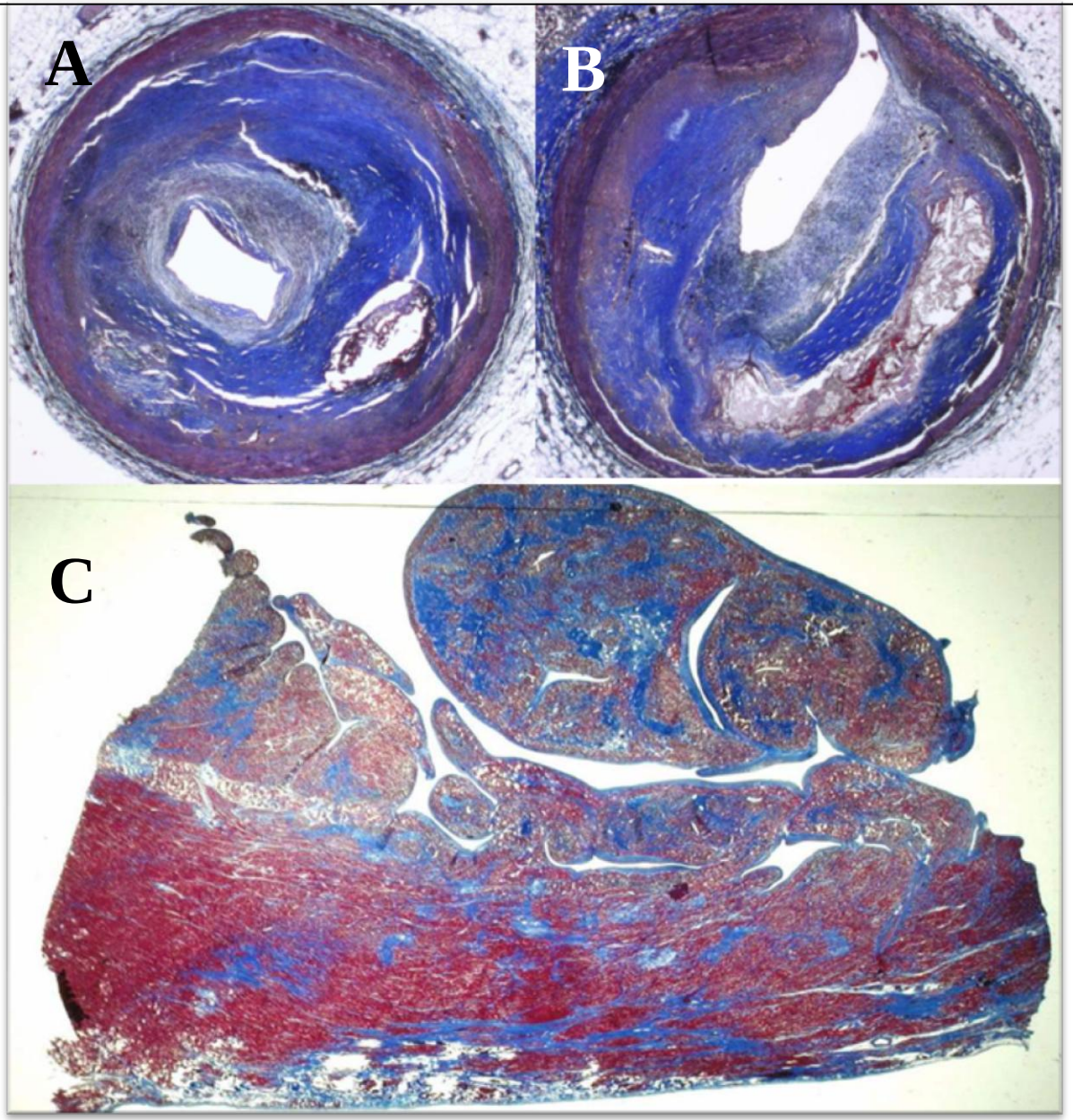
Profile of middle-aged victims of SCD during sports

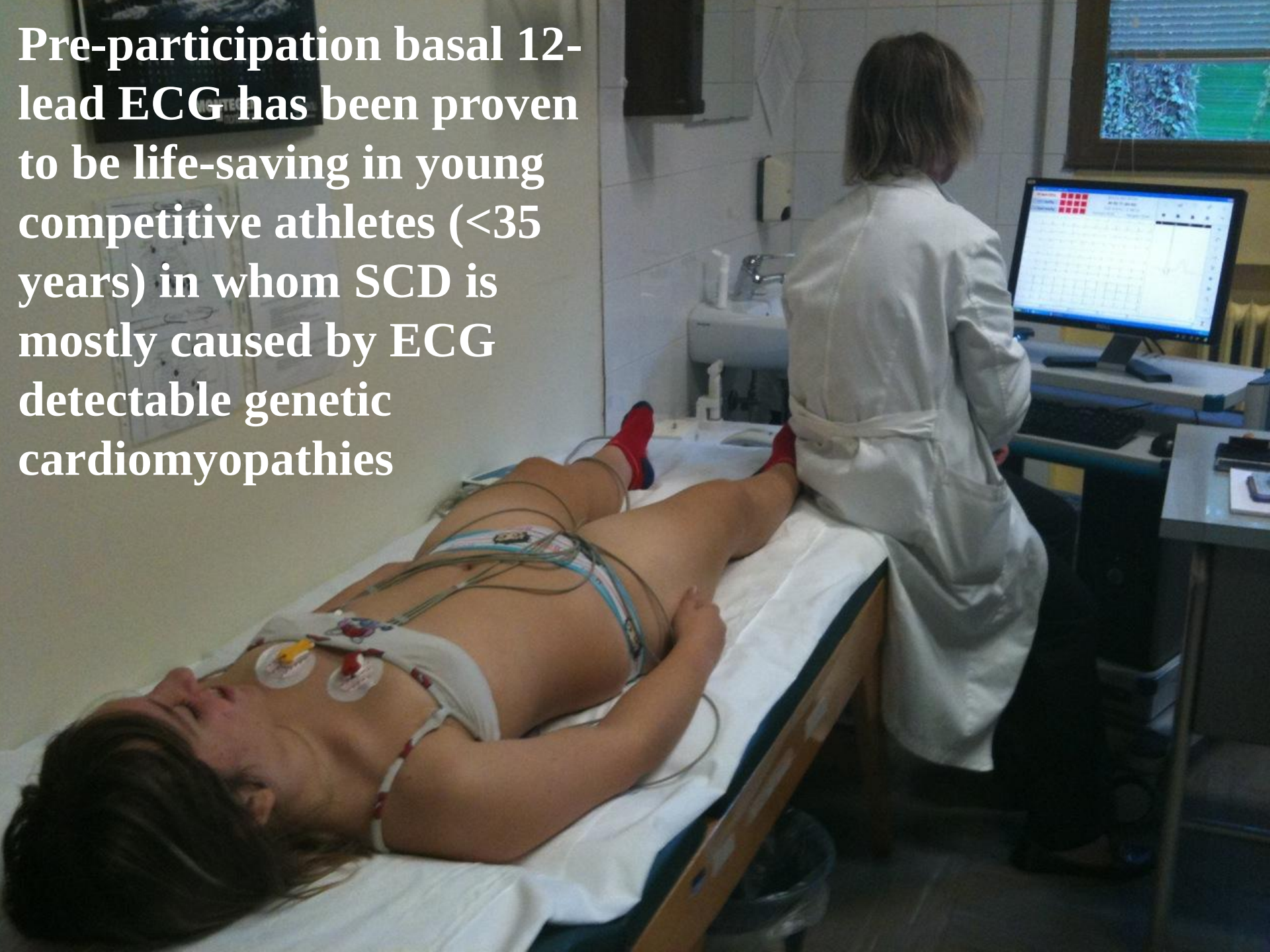
- adult man
- Asymptomatic
- No prior documentation of heart disease
- Cardiac arrest due to FV
- Post-mortem: atherosclerotic plaque lesions obstructing ≥one epicardial coronary vessel(s) in 71% to 87%

Sudden death of a 47-year old marathon runner

Obstructive atherosclerotic coronary artery disease of both left (anterior descending branch) and right coronary arteries (A,B)

C) Histology of the myocardium shows replacement type fibrosis due to previous myocardial infarction.




Pre-participation basal 12-lead ECG has been proven to be life-saving in young competitive athletes (<35 years) in whom SCD is mostly caused by ECG detectable genetic cardiomyopathies


Pre-participation basal 12-lead ECG appears to be a non accurate test for screening coronary artery disease in older athletes engaged in leisure-time sports such as Marathon running

Exercise test screening

Because of its established prognostic value, widespread availability
and low cost, exercise testing is widely deemed the best available test for screening asymptomatic adults prior to an exercise programme.

Exercise testing has a low predictive value for CAD in the general asymptomatic population, but in a patient population with risk factor for CAD it may identify patients with markedly increased risk for coronary events.

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SAGE

Cardiovascular evaluation of middle-aged/ senior individuals engaged in leisure-time sport activities: position stand from the sections of exercise physiology and sports cardiology of the European Association of Cardiovascular Prevention and Rehabilitation

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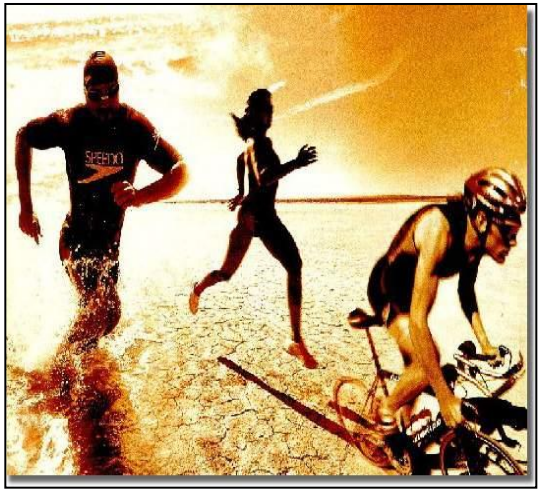
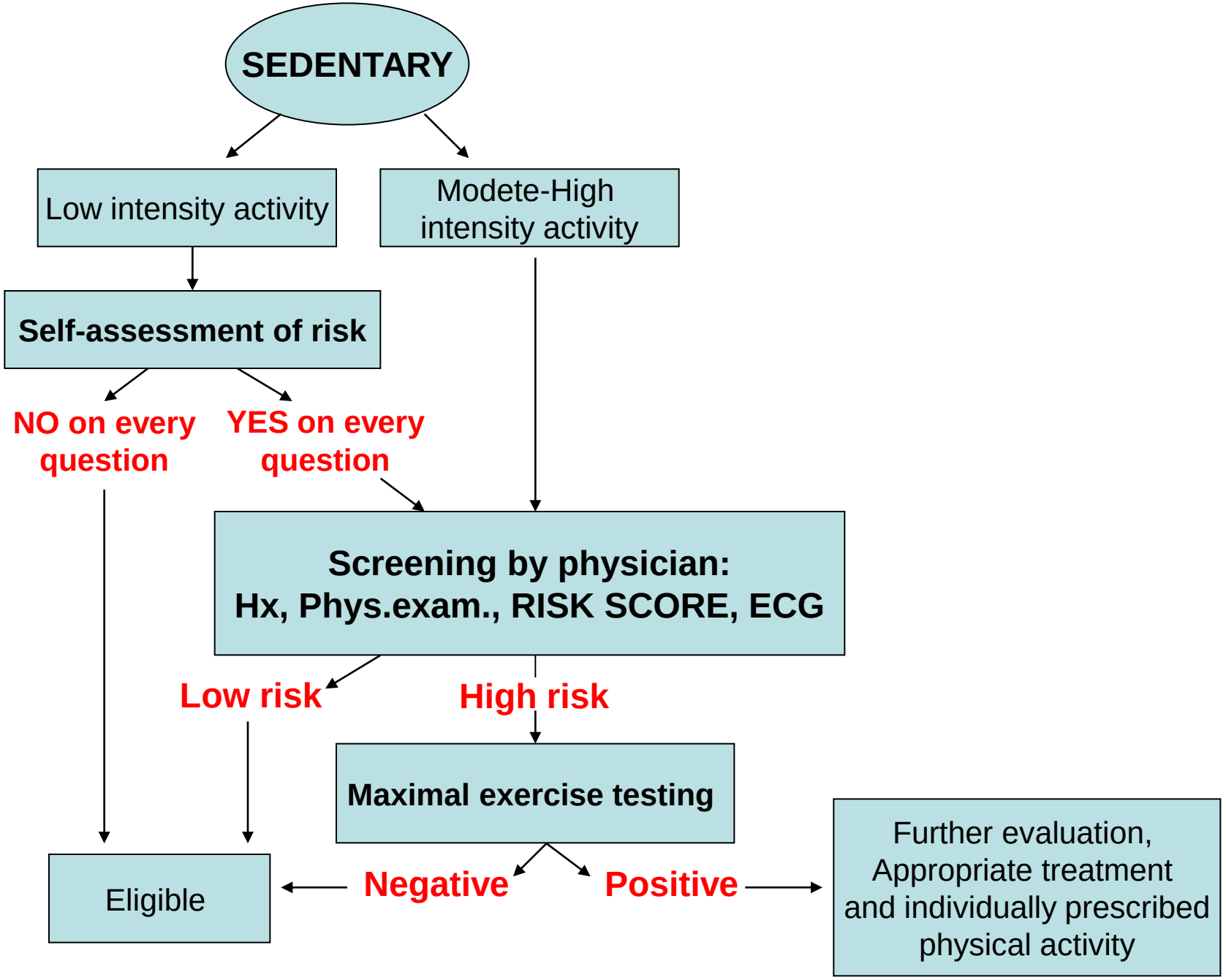
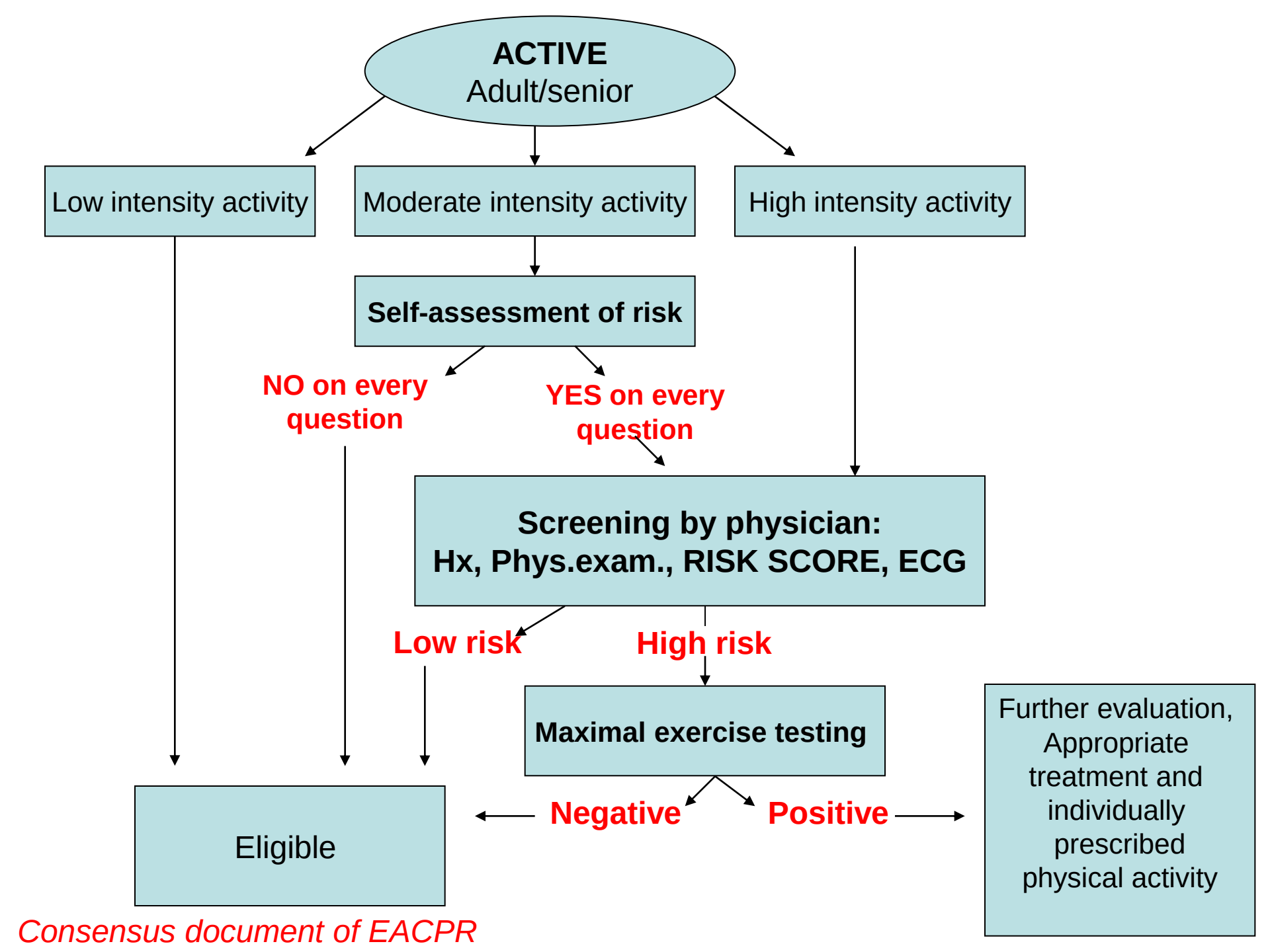




Consensus document of EACPR


ACTIVE
Adult/senior
Low intensity activity
Moderate intensity activity
High intensity activity
Self-assessment of risk
NO on every question
YES on every question
Screening by physician:
Hx, Phys.exam., RISK SCORE, ECG
Low risk
High risk
Maximal exercise testing
Negative
Positive
Eligible
Further evaluation, Appropriate treatment and individually prescribed physical activity
Consensus document of EACPR

Conclusions (1)

The available evidence indicates that ECG screening has to be considered an efficient health strategy for prevention of SCD of young competitive athletes.

At risk-cardiovascular diseases are accurately identified by ECG screening at a pre-symptomatic phase.

Early identification and management of asymptomatic athletes favourably modify the outcome of the underlying diseases leading to substantial prevention of in-the-field mortality.

Conclusions (2)

Identification of middle-aged/senior athletes with coronary artery disease at risk of SCD is difficult and the utility of preparticipation screening by means of resting and exercise ECG testing remains unproven.

Cardiovascular medical evaluation is recommended by most Associations of Cardiology and Sports Medicine as a prudent measure before entering leisure-time sport activity in the light of our current understanding of the cardiovascular risks and benefits of exercise in this age group.