Exercise Stress Testing

May 2011

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- ST interpretation
  - Interpretable ECGs
  - Different patterns
    - Stress or recovery
    - Resting abnl
    - ST elev
    - PR seg dprsn
- Hemodynamics/Clinical

Exercise Stress Testing

- ACC/AHA 2002 “Guideline Update for Exercise Testing”; Task Force on Practice Guidelines, Committee on Exercise Testing, Raymond J. Gibbons, Chair.
- AHA Scientific Statement, “Exercise Standards for Testing and Training, A Statement for Healthcare Professionals From the AHA” Circulation 2001; 104:1694.
- Chaitman, BR. Chapter 13, “Exercise Stress Testing” in Braunwald’s Heart Disease, 8th ed. 2008.

Exercise Physiology - Acute Effects

$R.Q. = V_{CO_2}/V_{O_2}$

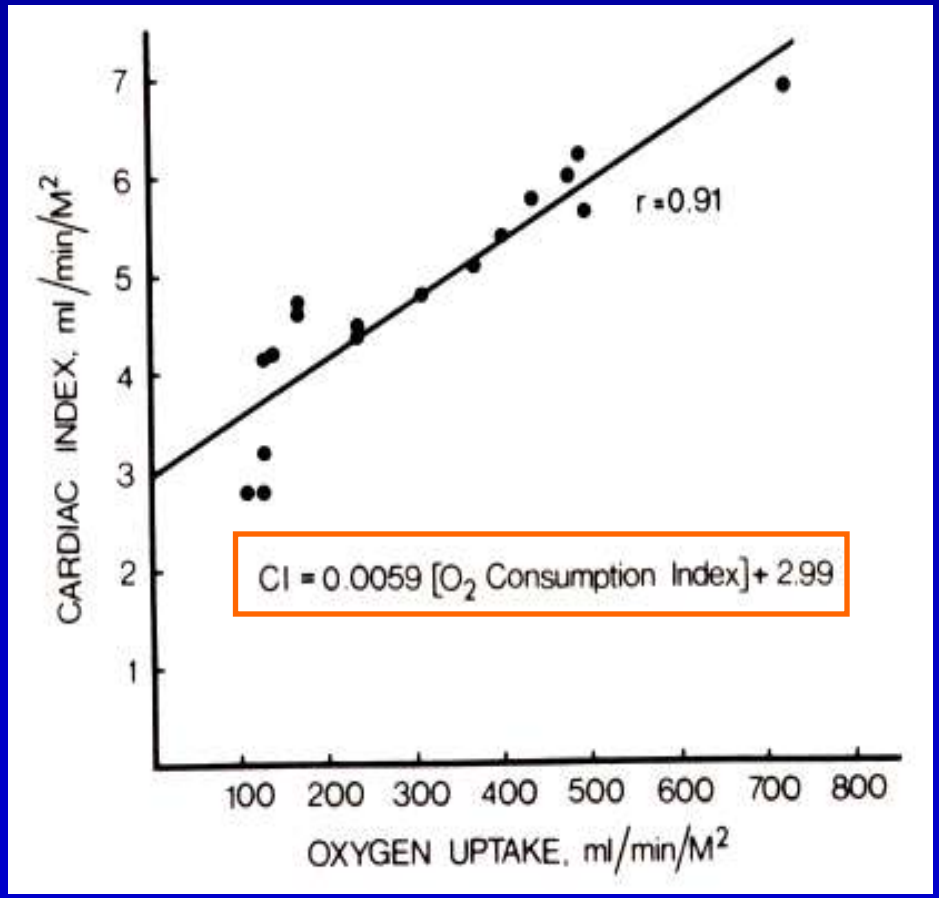
- Cardiac Output ↑
  - (Stroke volume ↑, Heart Rate ↑)
- Oxygen Extraction ↑
  - (Arteriovenous O_2 difference ↑, "A-V O_2 difference")
- Metabolic change
  - more carbohydrate metabolism, less fat
  - hepatic gluconeogenesis, use of muscle glycogen
  - Respiratory quotient ↑ (resting ~0.7, exercise ~1.0)
- Blood flow distribution from splanchnic to muscle

Oxygen Consumption and Cardiac Output

Data in 7 normal subjects.

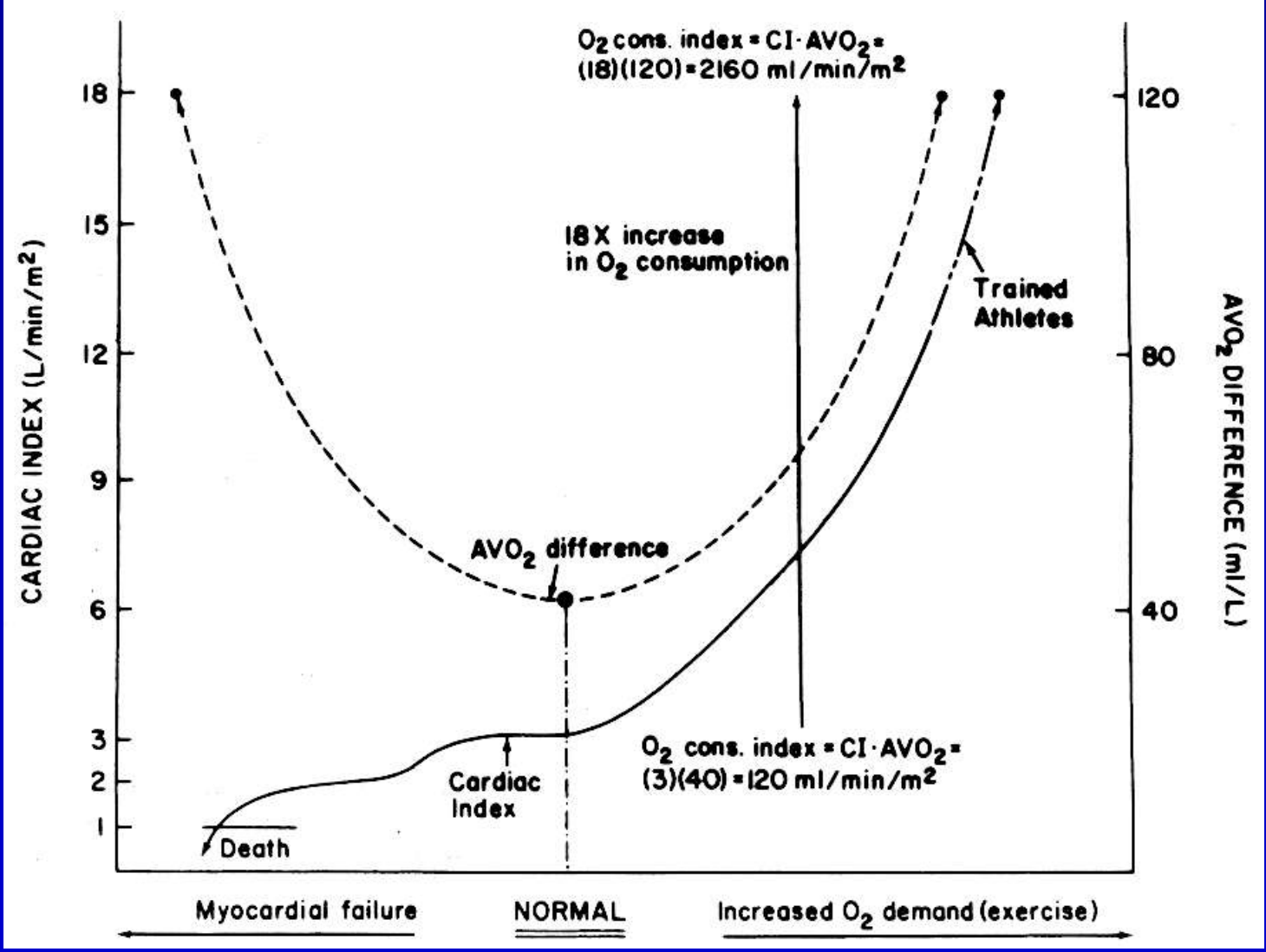
Exercise Factor:
C.O. should increase by 600cc/min for each 100cc/min increase in Oxygen consumption:
$\Delta C.O./\Delta O_2 \geq 6$.

Measured C.O. should be >0.8 of predicted.



From Grossman, 5th ed, 1996, p. 283; original 1951 Dexter et al.

Blood Flow: Cardiac Output



From Grossman, 1996, p. 160

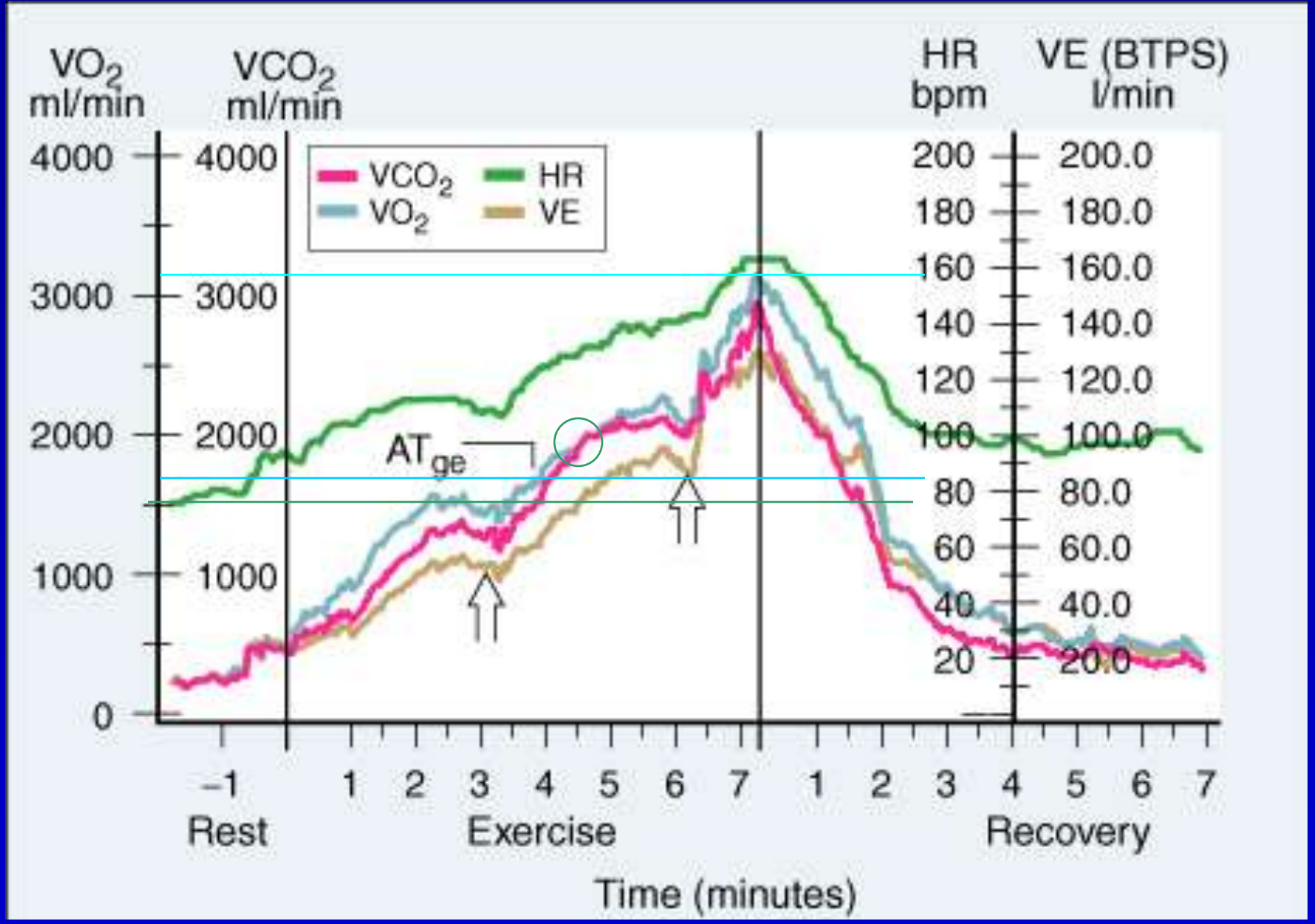
Cardiac Output in Man

Circulation	Rest	%	Exercise	%	Δ
Splanchnic	1400	24	600	3	.43
Renal	1100	19	600	3	.55
Cerebral	750	13	750	5	1.0
Coronary	250	4	750	5	3.0
Skeletal muscle	1200	21	12500	71	10.4
Skin	500	9	1900	11	3.8
Other	600	10	400	2	.67
Total	5800	100	17500	100	3.0

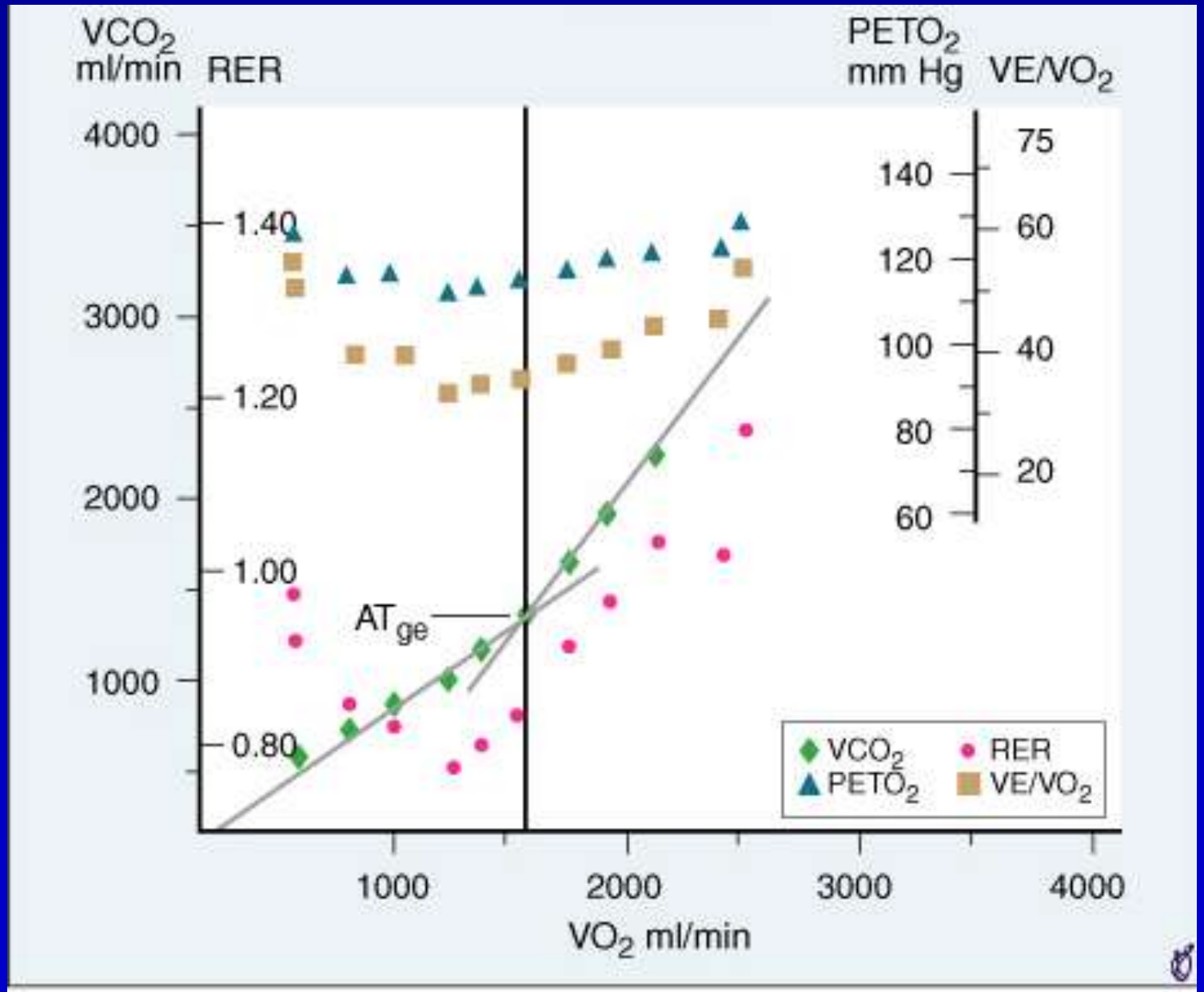
Wade OL and Bishop JM 1962. 10 minutes of strenuous exercise

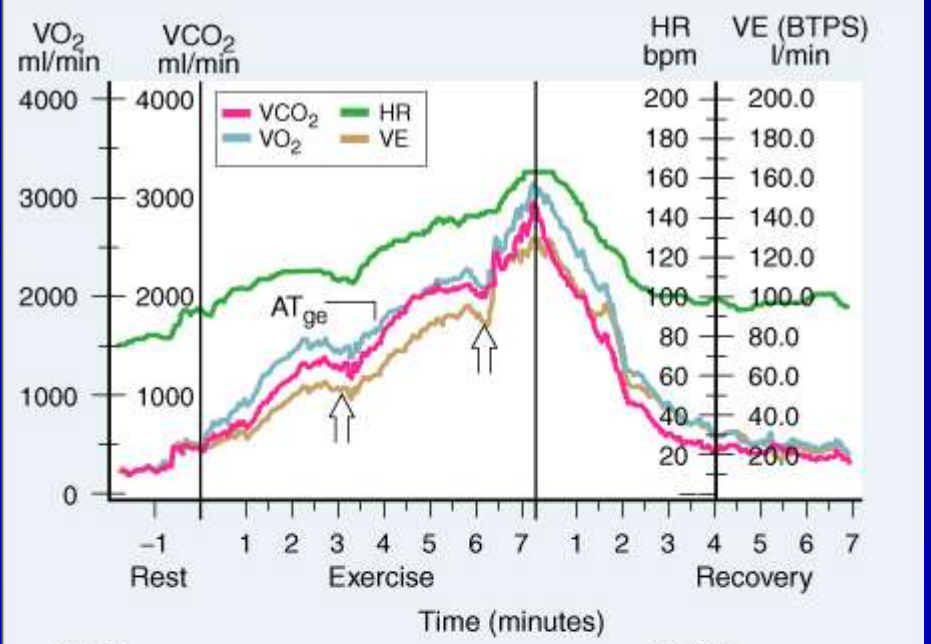
Exercise Physiology - Pulmonary Effects

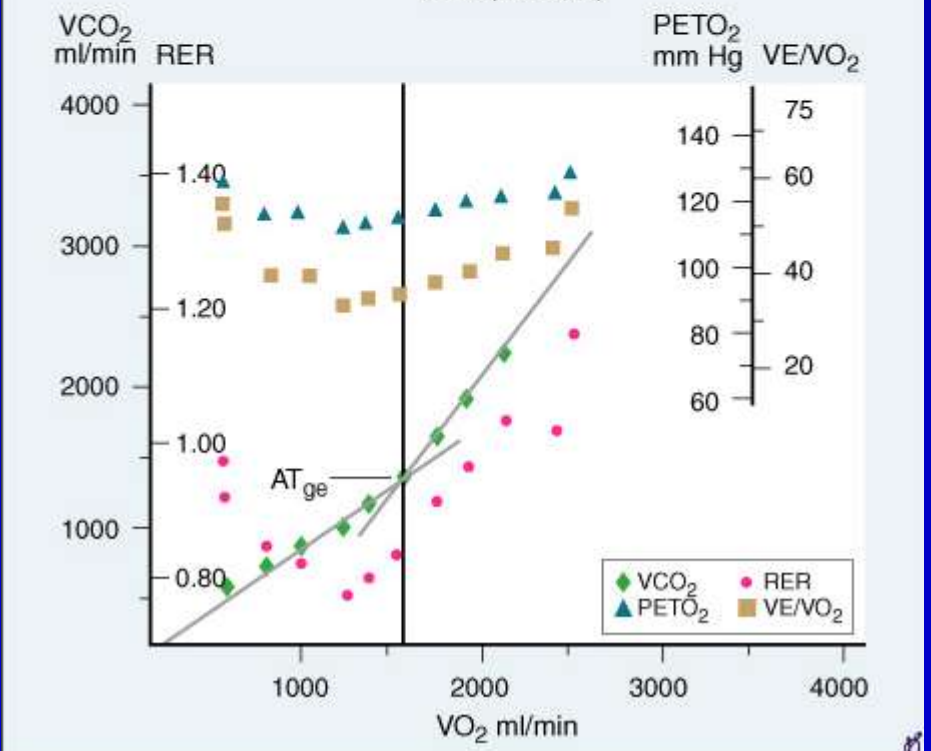
- Progressive increase in minute ventilation, especially above anaerobic threshold
- Above anaerobic threshold - accumulation of H^+
  - skeletal muscle weakness
  - RQ >1.0
  - severe dyspnea
  - exhaustion



Bruce. Arrows indicate Stage change. Peak O2 3.08 L/min. AT (anaerobic threshold) 1.5 L/min (49% peak)

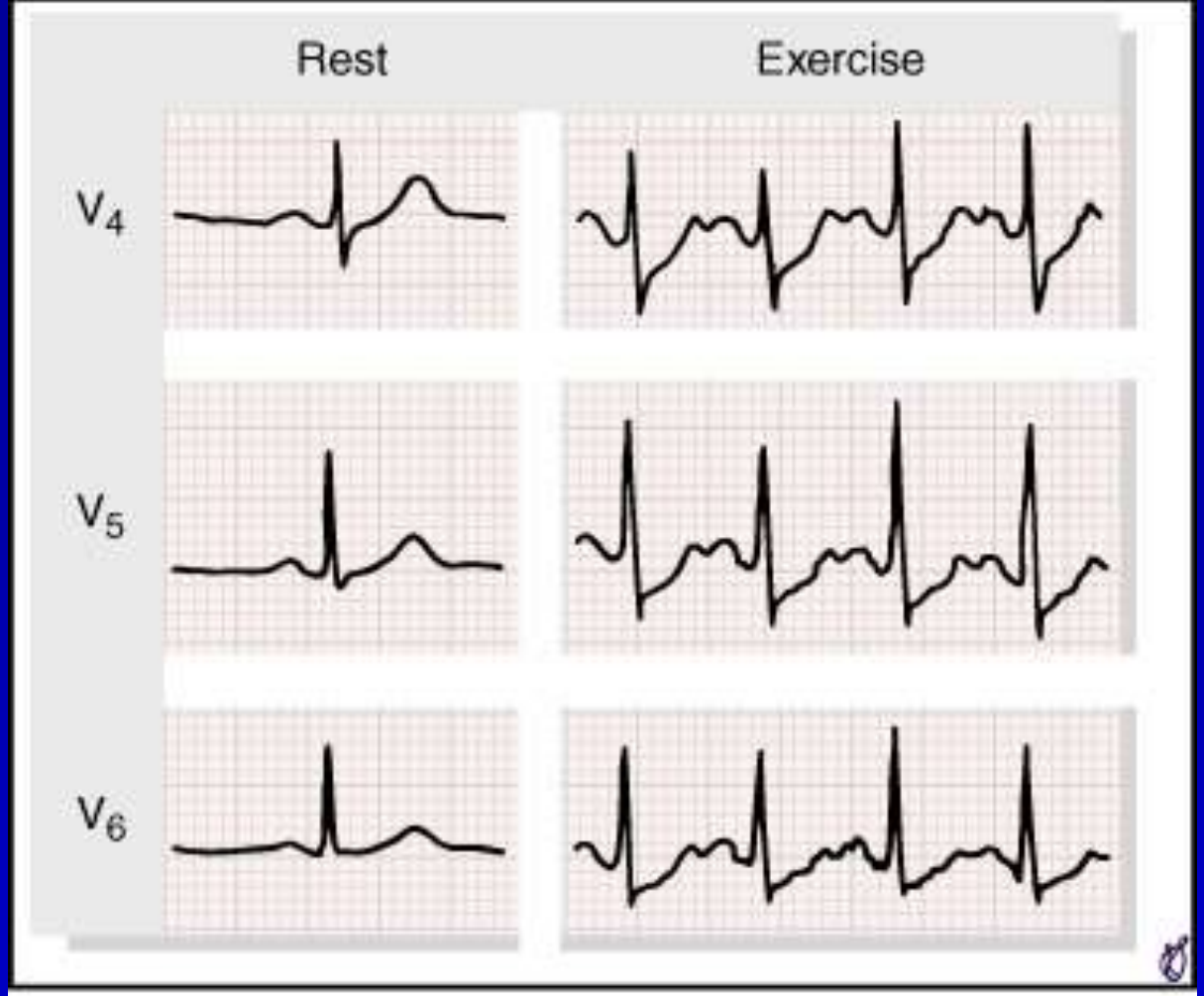


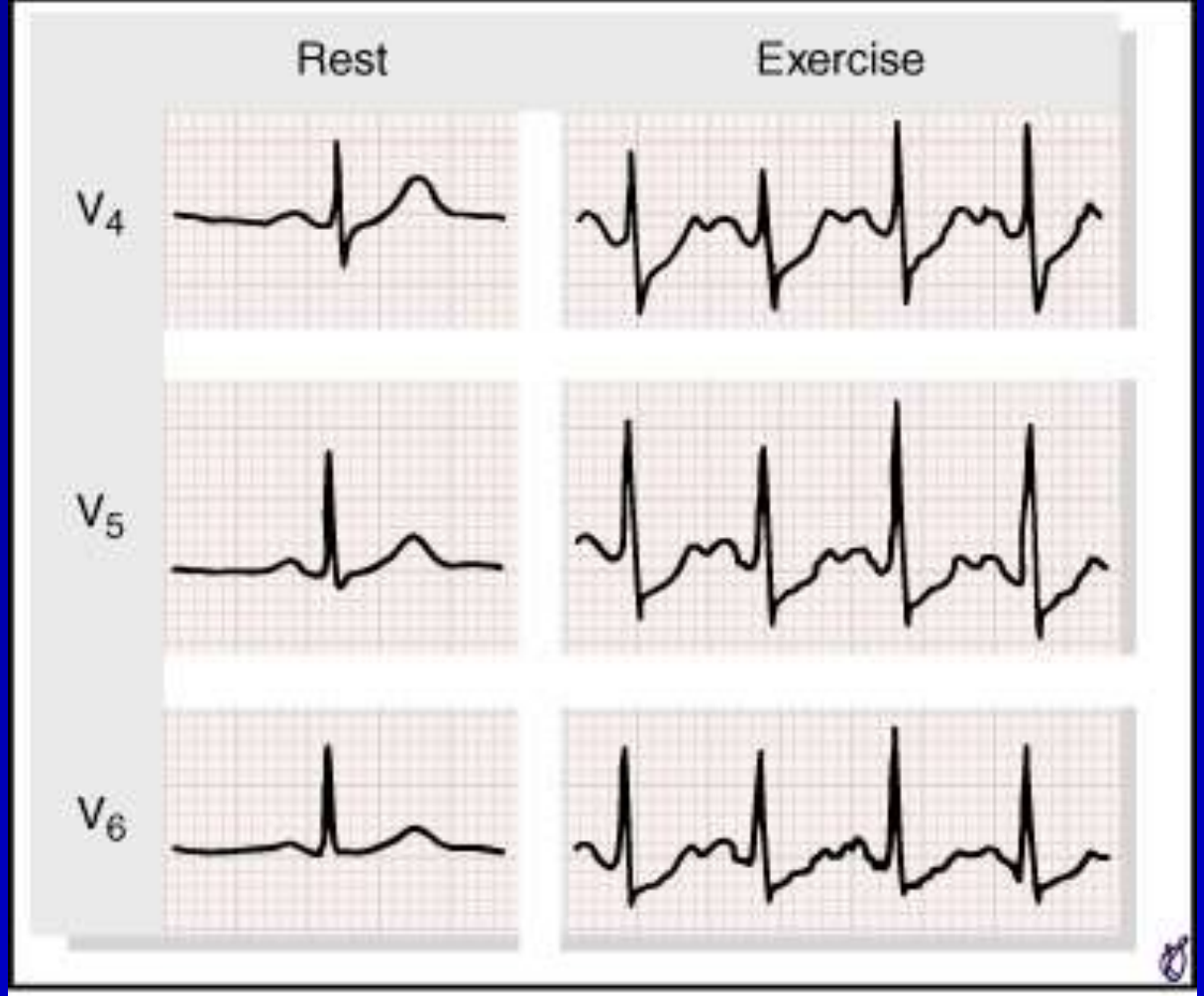




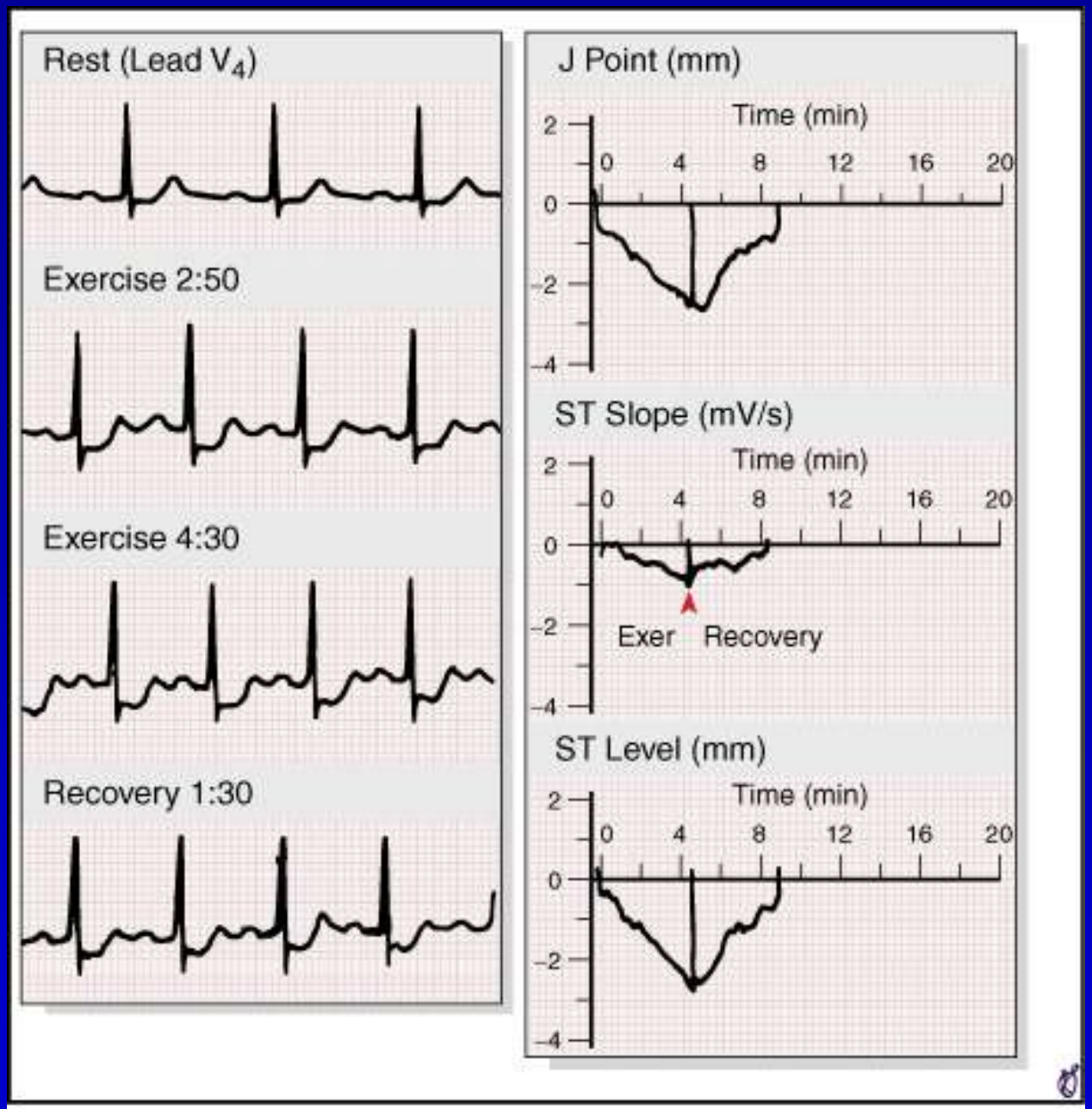
Functional Class	Clinical Status	O_2 Cost ml/kg/min	METs	Bicycle Ergometer	Treadmill Protocols															
				1 watt = 6 kpds	Bruce		Cornell		Balke-Ware	ACIP		mACIP		Naughton			Weber			
					3-min stages		2-min stages		% grad at 3.3 mph	2-min stages First 2 stages 1 min				2-min stages			2-min stages			
					MPH	%GR			1-min stages						%GR 3 MPH	%GR 3.4 MPH				
				For 70 kg body weight	5.5	20	MPH	%GR	26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1	MPH	%GR	MPH	%GR		32.5					
Normal and I	Healthy dependent on age, activity	56.0	16		5.0	18	5.0	18							30	24				
		52.5	15	KPDS			4.6	17		3.4	24	3.4	24		27.5	22				
		49.0	14	1500											25	20				
		45.5	13		4.2	16	4.2	16		3.1	24	3.1	24		22.5	18				
		42.0	12	1350											20	16	MPH	%GR		
		38.5	11	1200			3.8	15		3	21	2.7	24		17.5	14	3.4	14.0		
		35.0	10	1050	3.4	14	3.4	14		3	17.5	2.3	24	%GR 2 MPH	15	12	3.0	15.0		
		31.5	9	900			3.0	13		3	14	2	24		12.5	10	3.0	12.5		
		28.0	8	750										17.5	10	8	3.0	10.0		
		24.5	7	600	2.5	12	2.5	12		3	10.5	2	18.5	14	7.5	6	3.0	7.5		
II	Sedentary healthy	21.0	6				2.1	11						10.5	5	4	2.0	10.5		
		17.5	5	450	1.7	10	1.7	10		3.0	7.0	2	13.5							
III	Limited	14.0	4	300	1.7	5	1.7			3.0	3.0	2	7	7	2.5	2	2.0	7.0		
		10.5	3							2.5	2.0	2	3.5	3.5	0		2.0	3.5		
		7.0	2	150	1.7	0	1.7	0		2.0	0	2	0	0			1.5			
IV	Symptomatic	3.5	1														1.0	0		

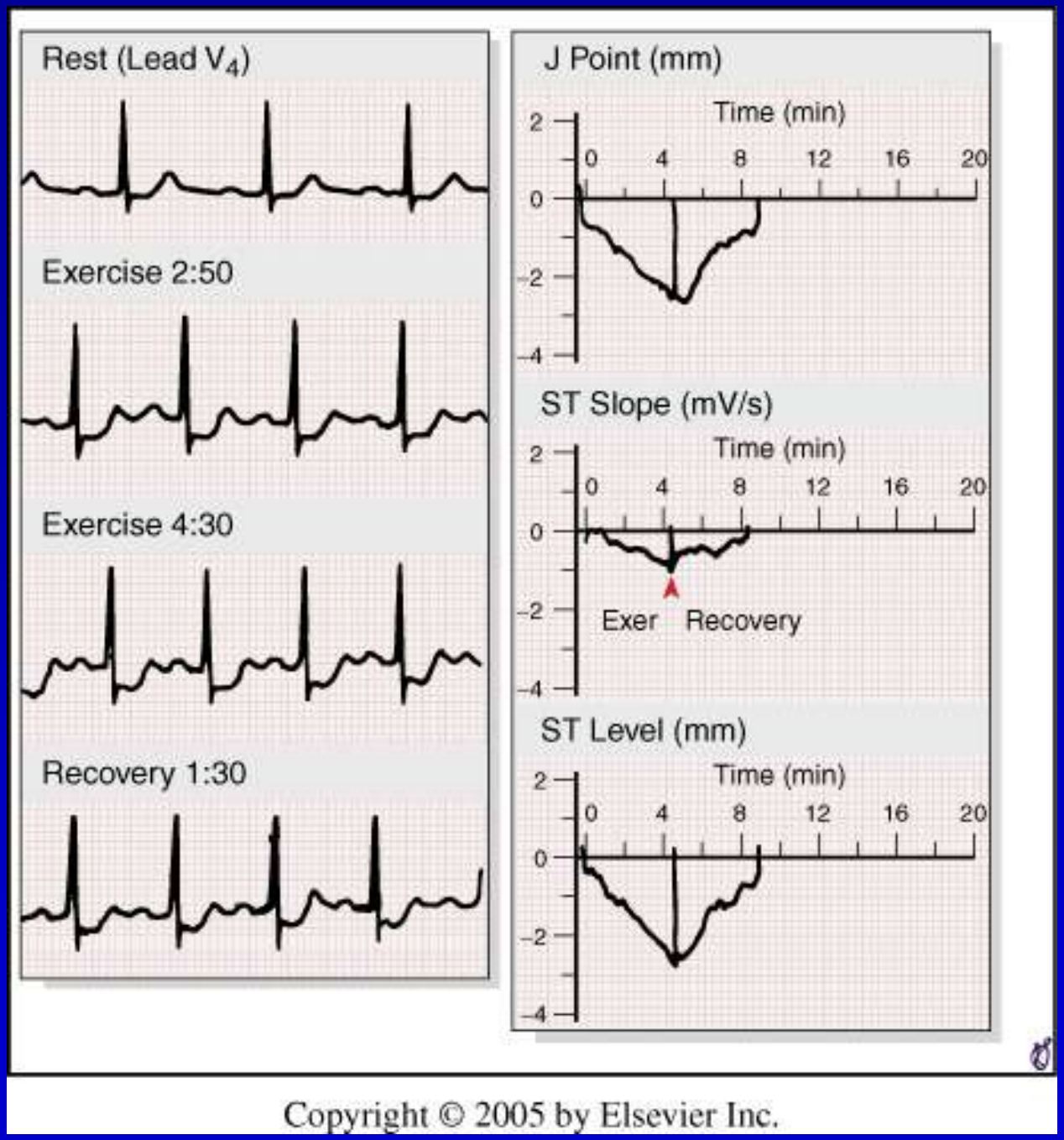
ECG Response in Stress Testing





J point depression of 2 to 3 mm in leads V4 to V6 with rapid upsloping ST segments depressed approximately 1mm 80msec after the J point. The ST segment slope in leads V4 and V5 is 3.0mV/sec. This response should not be considered abnormal.





severe ischemic response

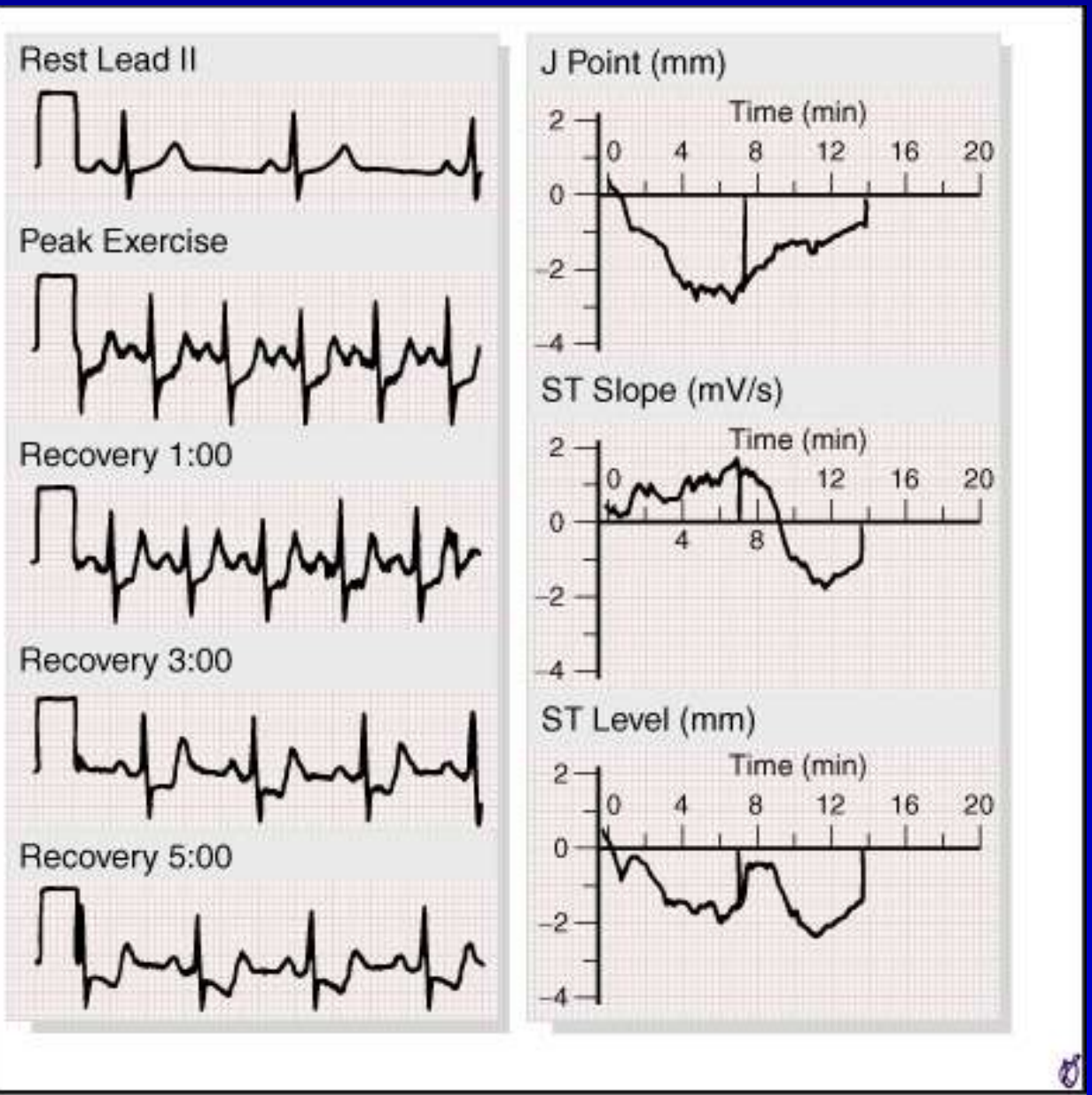
Lots mm

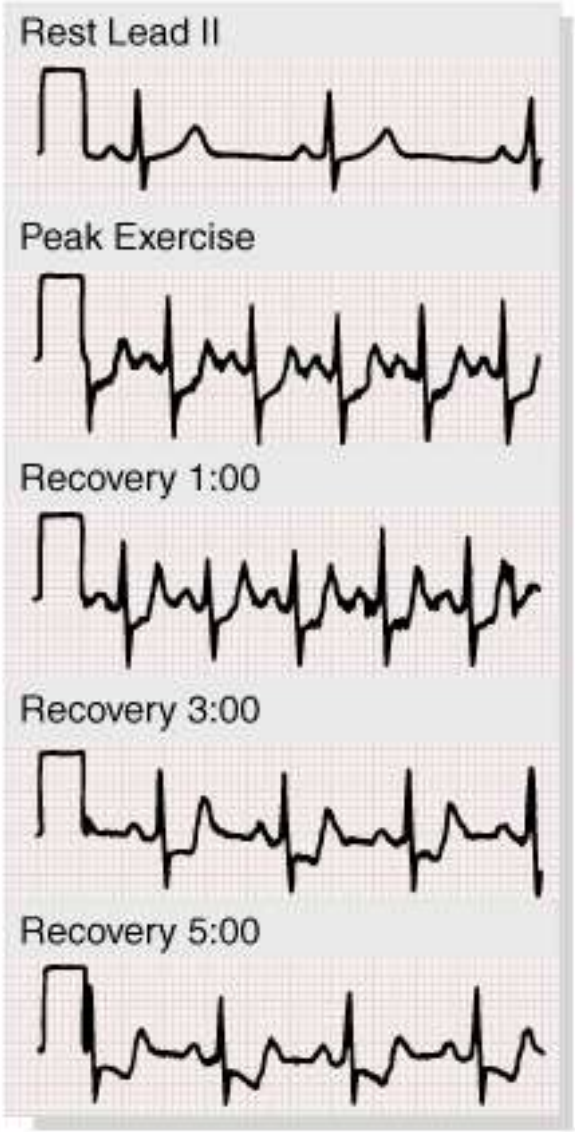
Long duration

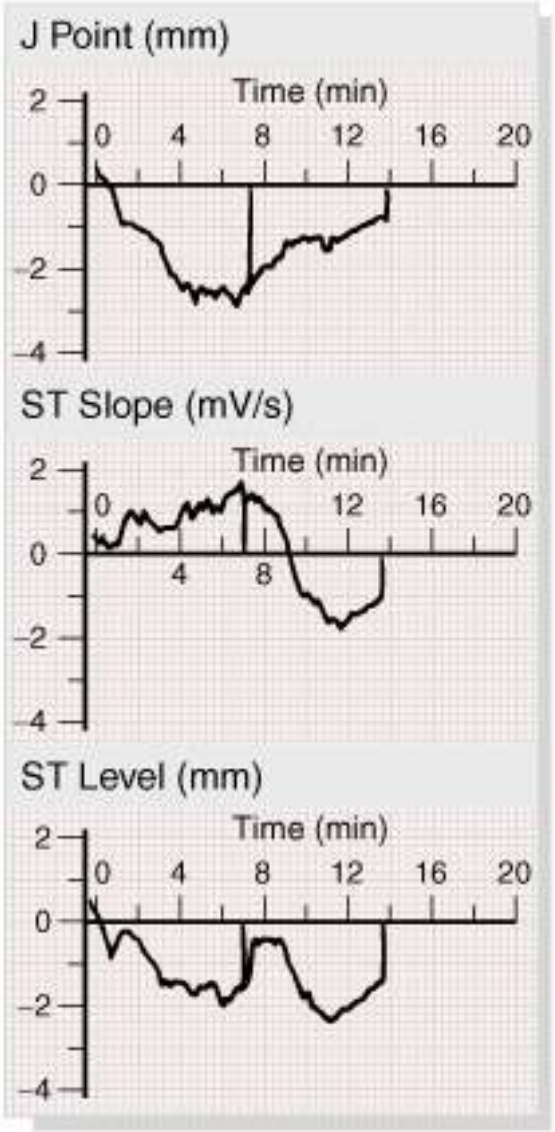
Early onset

Multiple leads

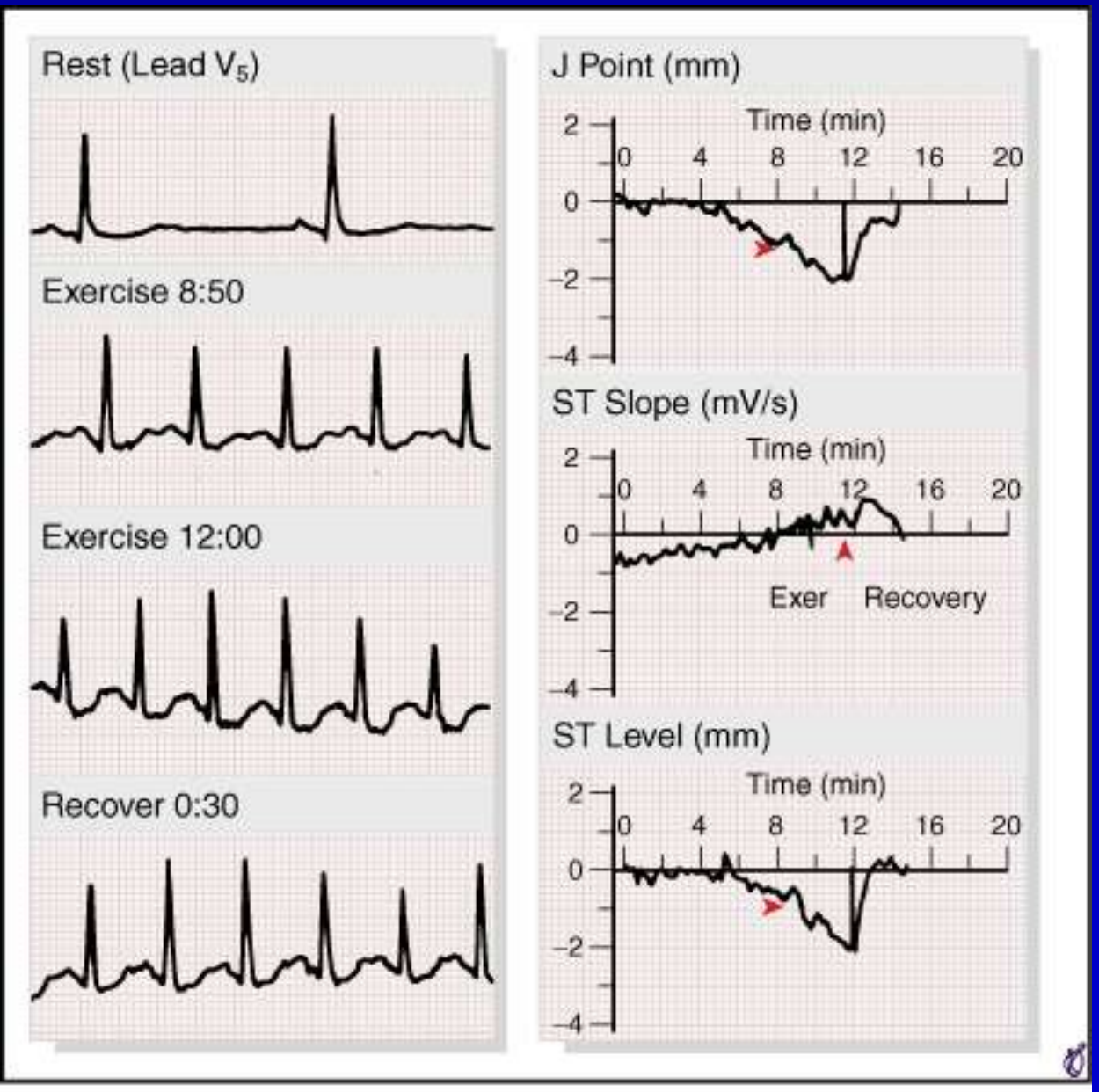
Low Hr/DP

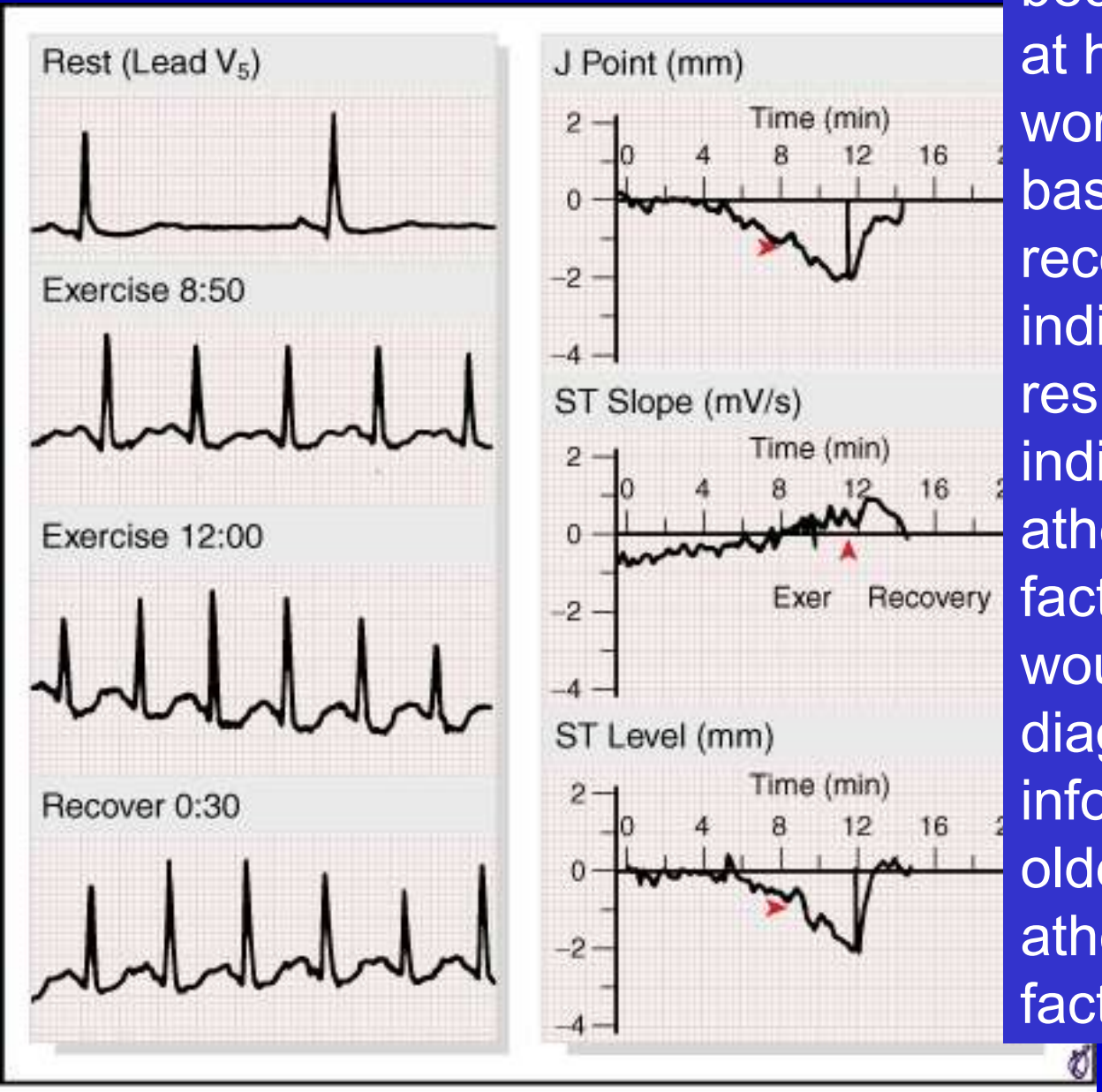




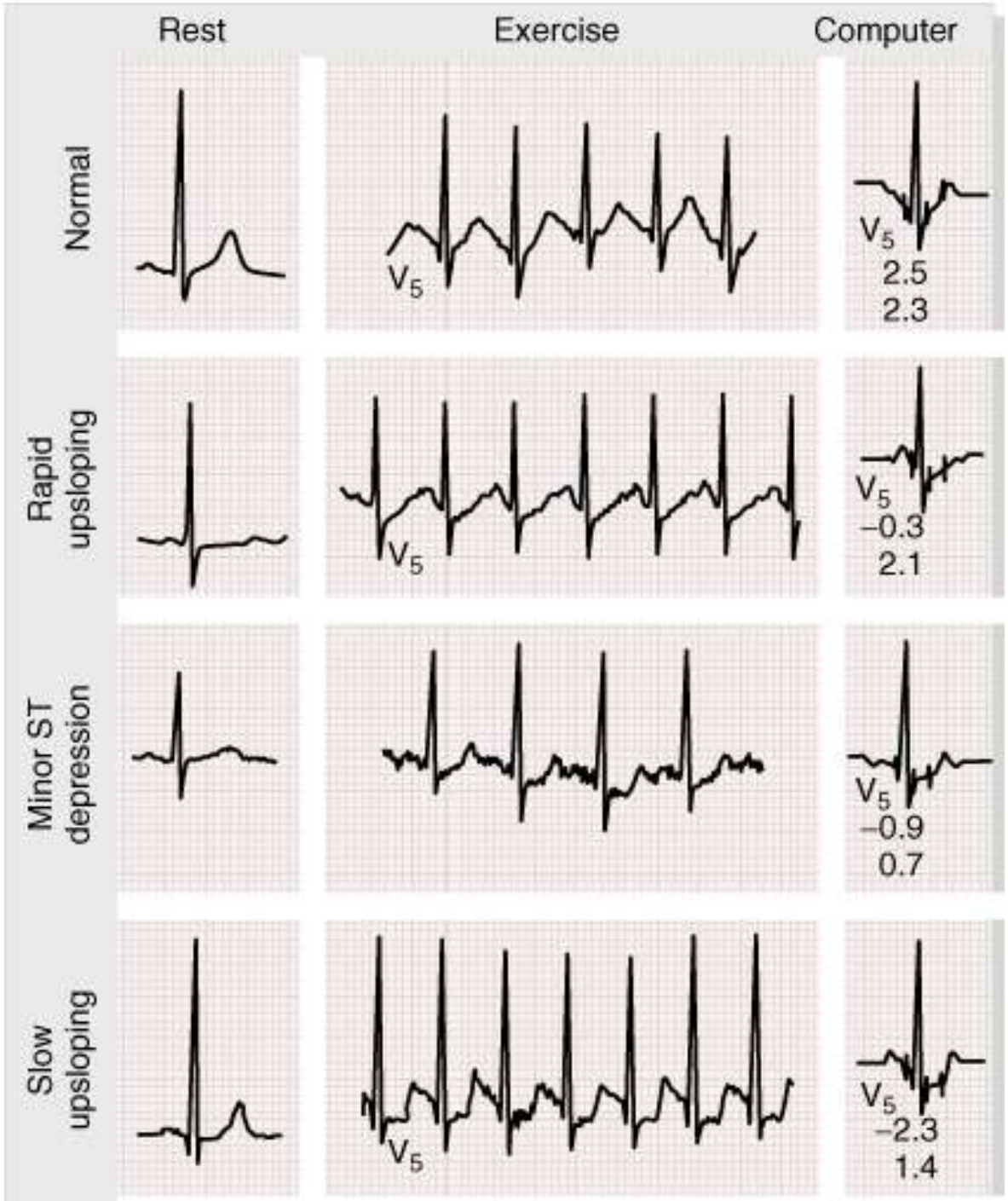


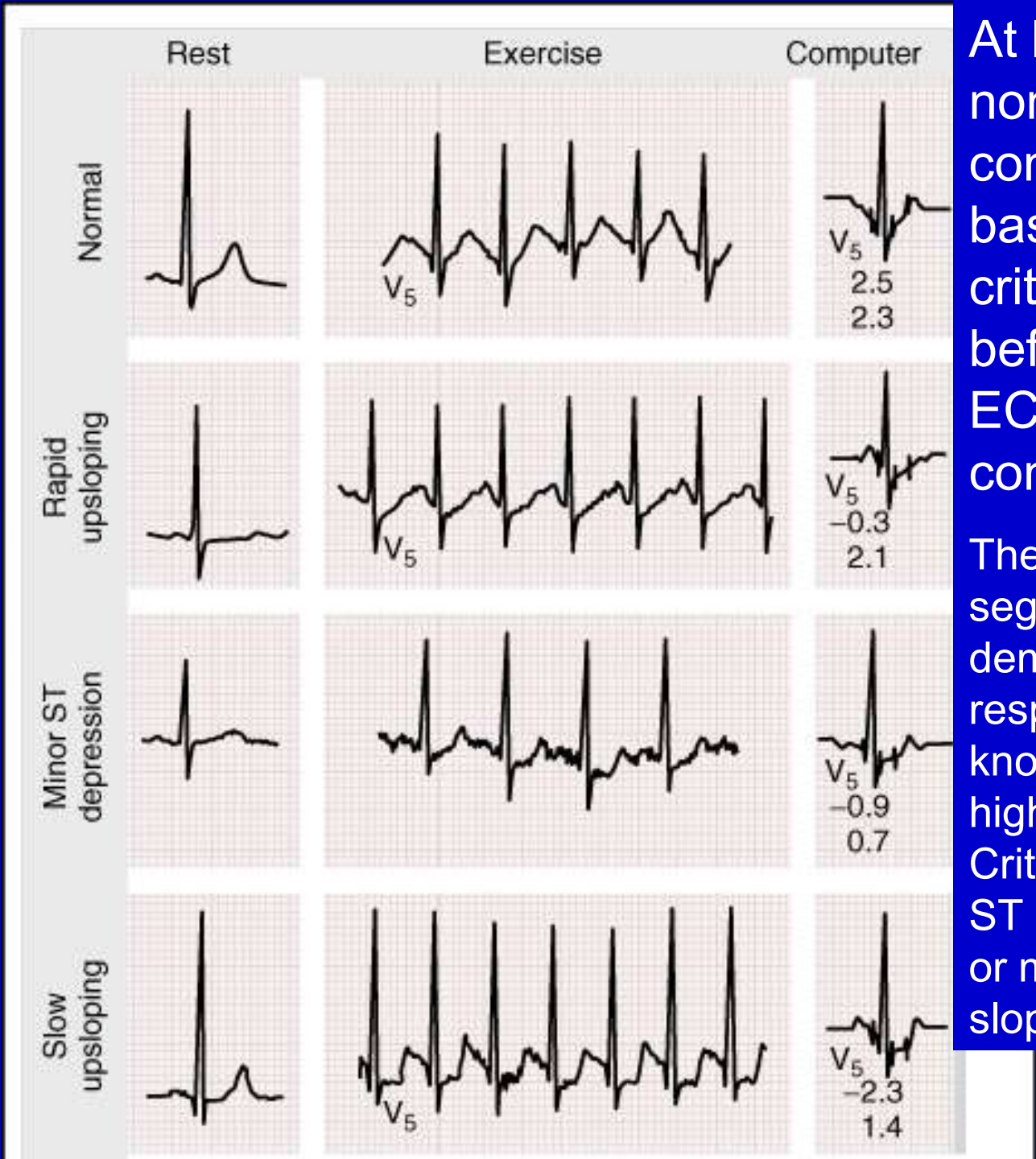
This “ slow upsloping” ST segment at peak exercise indicates an ischemic pattern in patients with a high pretest prevalence of coronary disease. A typical ischemic pattern is seen at 3 minutes of the recovery phase when the ST segment is horizontal and 5 minutes after exertion when the ST segment is downsloping.





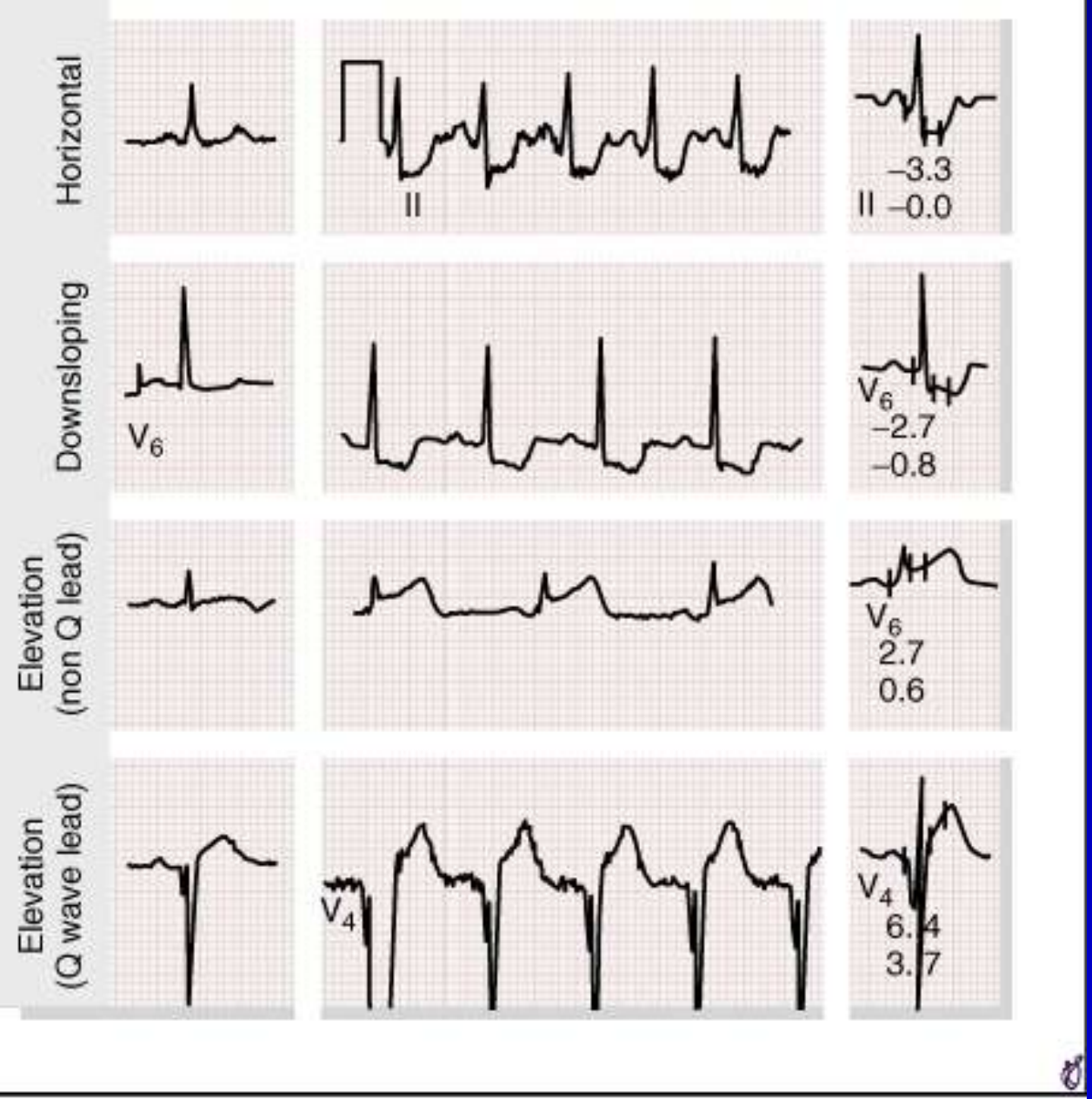
The ST segment becomes abnormal only at high exercise workloads and returns to baseline in the immediate recovery phase may indicate a false-positive result in an asymptomatic individual without atherosclerotic risk factors. Stress imaging would provide more diagnostic and prognostic information if this were an older person with several atherosclerotic risk factors.

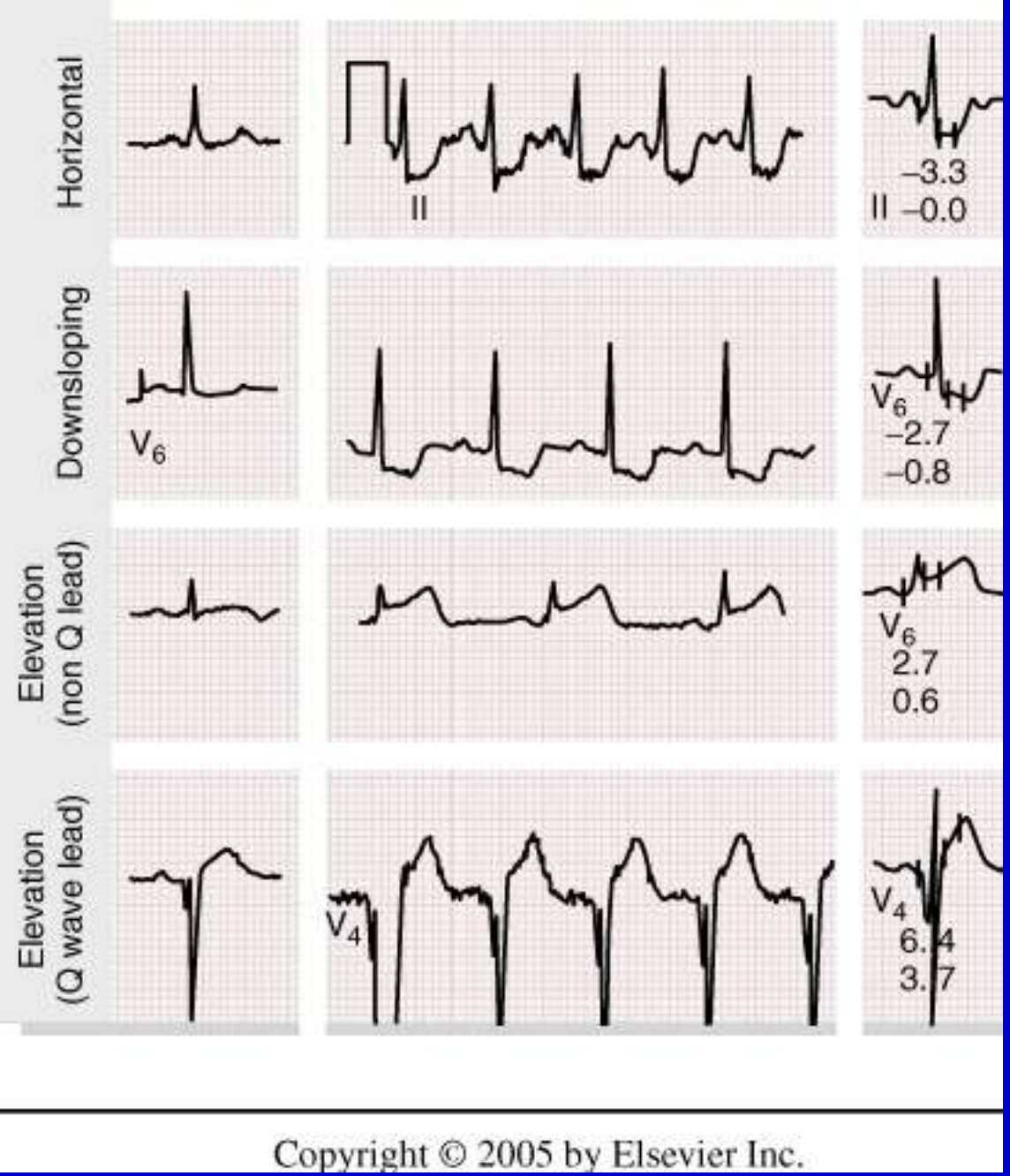

Rest
Exercise
Computer
Normal
V5
V5
2.5
2.3
Rapid upsloping
V5
V5
–0.3
2.1
Minor ST depression
V5
–0.9
0.7
Slow upsloping
V5
V5
–2.3
1.4



At least three noncomputer average complexes with a stable baseline should meet criteria for abnormality before the exercise ECG result can be considered abnormal.

The slow upsloping ST segment pattern often demonstrates an ischemic response in patients with known coronary disease or high pretest clinical risk. Criteria include J point and ST 80 depression of 0.15mV or more and ST segment slope of less than 1.0mV/sec

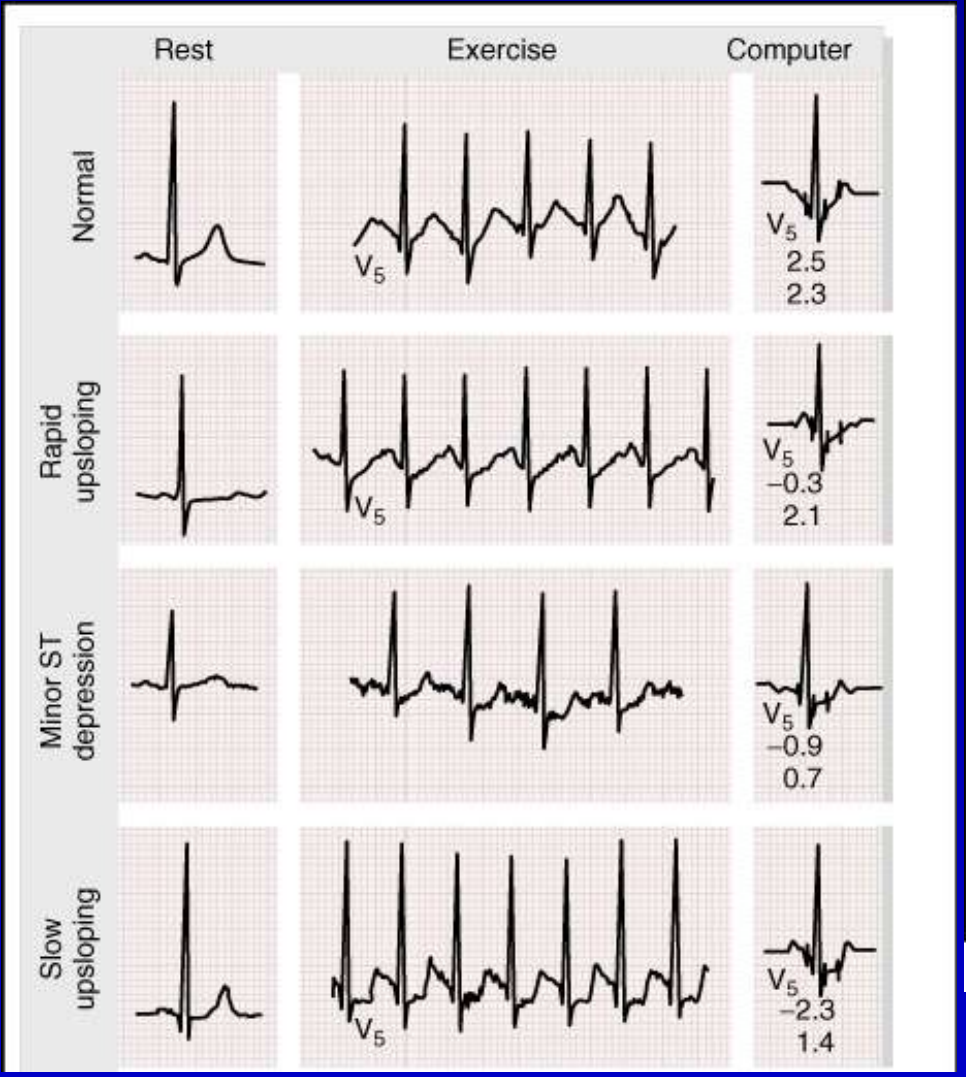


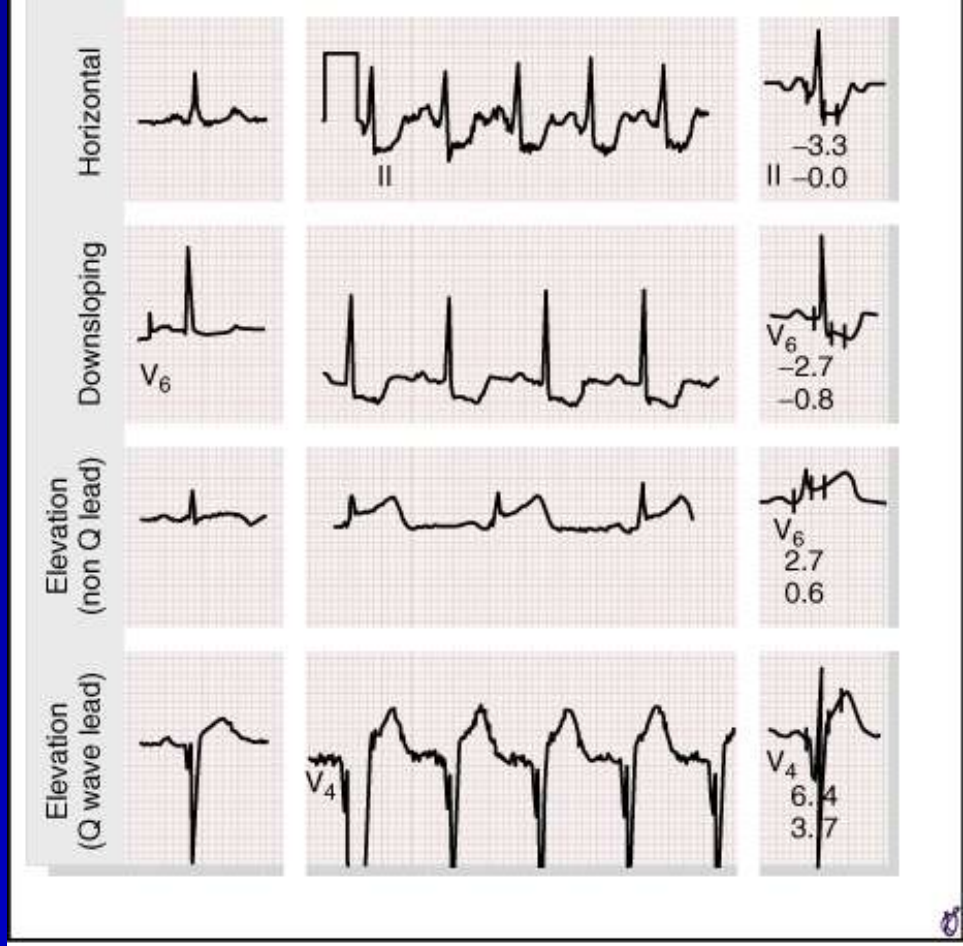


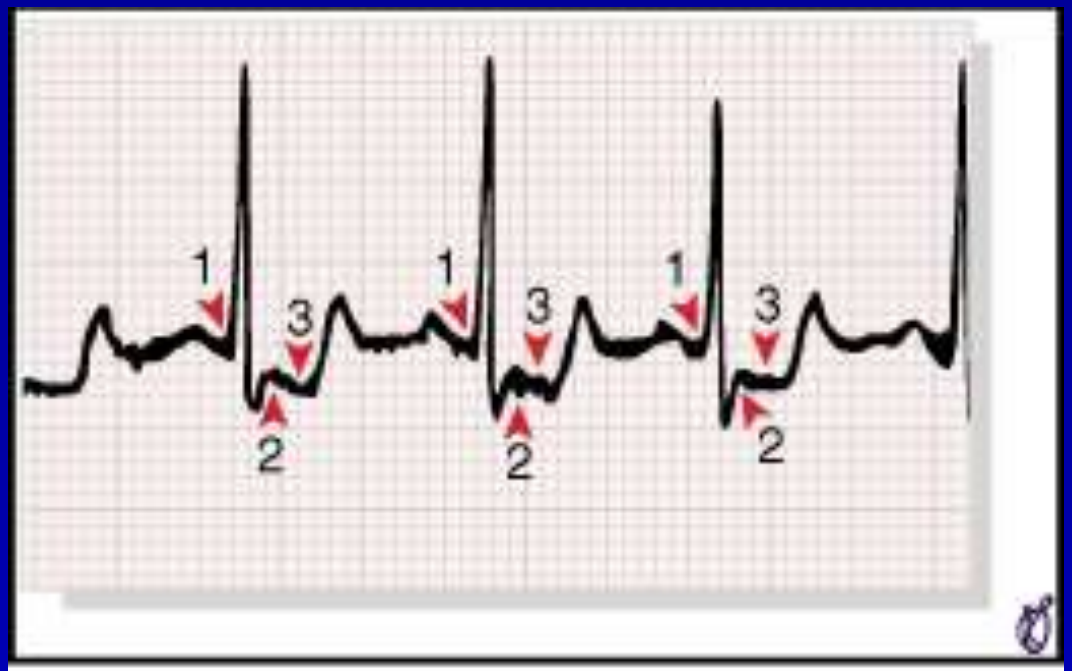
Classic ischemia - horizontal ST segment depression of both the J point and ST 80 depression are 0.1mV or more and ST segment slope is within the range of 0.0 mV/sec.

Downsloping ST segment slope is − 1.0mV/sec.

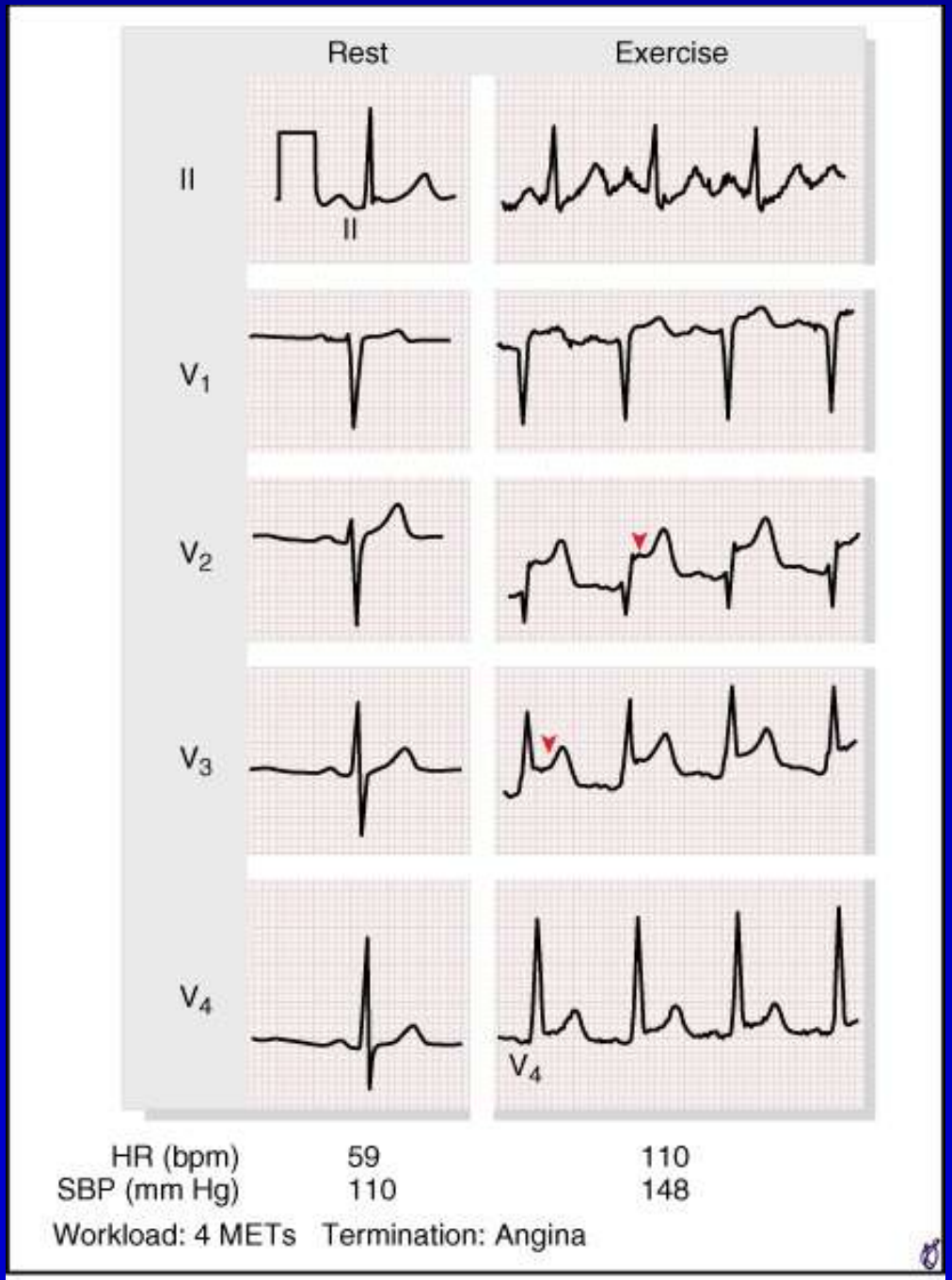
ST segment elevation in a non-Q wave noninfarct lead occurs when the J point and ST 60 are 1.0mV or greater and represents a severe ischemic response

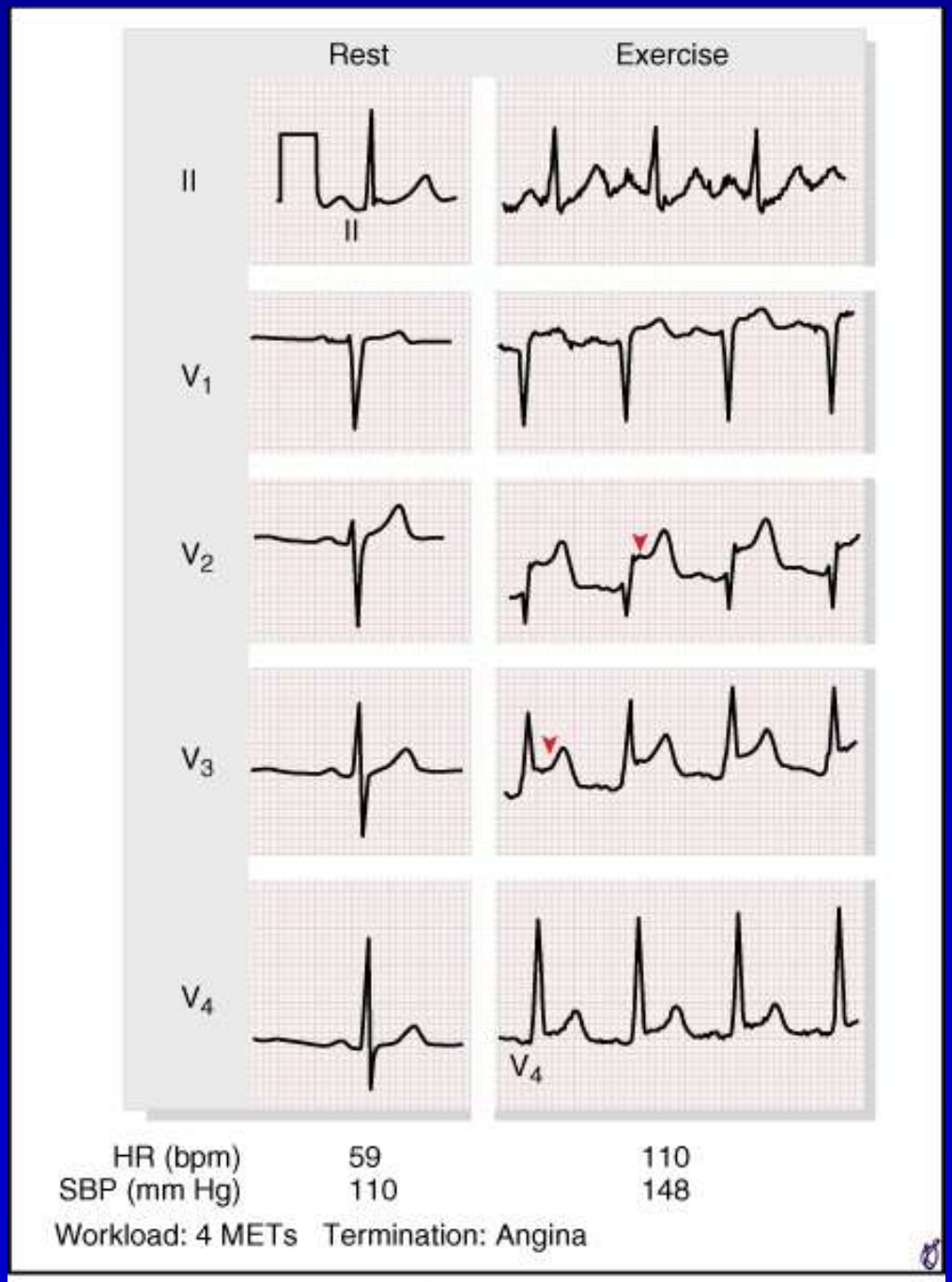




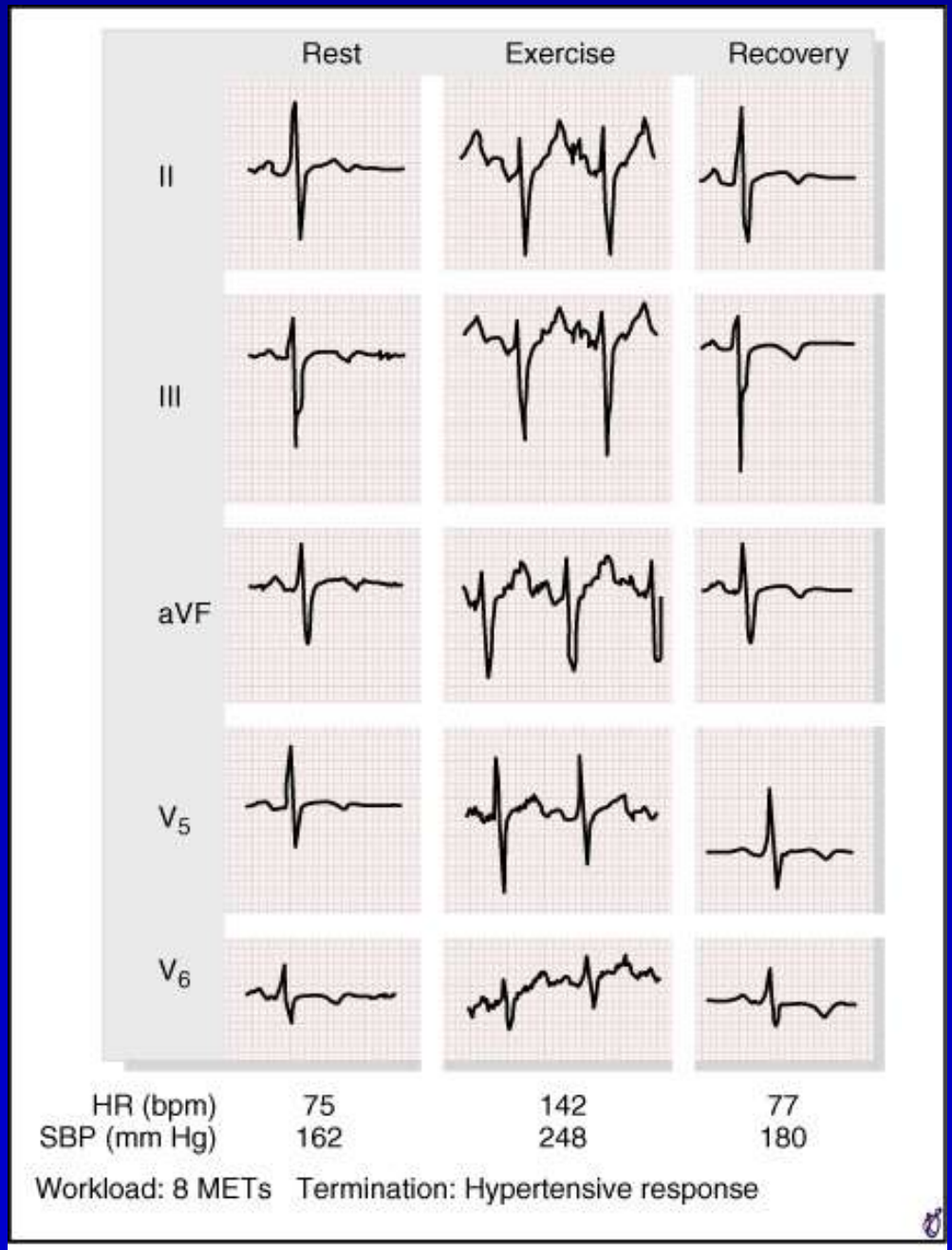


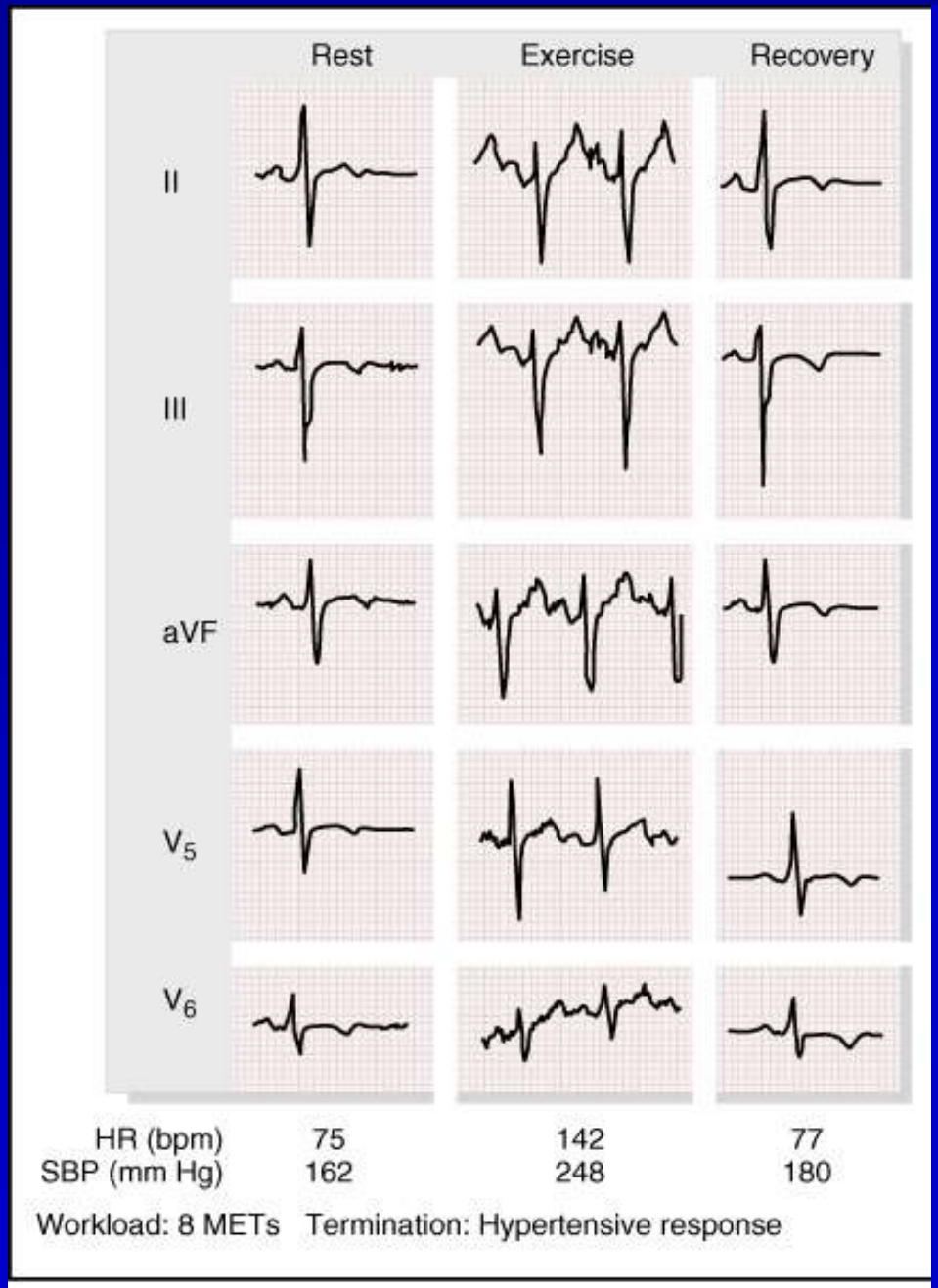
Three consecutive complexes with a relatively stable baseline are selected. The PQ junction (1) and J point (2) are determined; the ST 80 (3) is determined at 80 msec after the J point. In this example, average J point displacement is 0.2mV (2mm) and ST 80 is 0.24mV (24mm). The average slope measurement from the J point to ST 80 is −1.1 mV/sec





This ECG pattern is usually associated with a full-thickness, reversible myocardial perfusion defect in the corresponding left ventricular myocardial segments and high-grade intraluminal narrowing at coronary angiography. Rarely, coronary vasospasm.





Pseudonormalization of T waves.

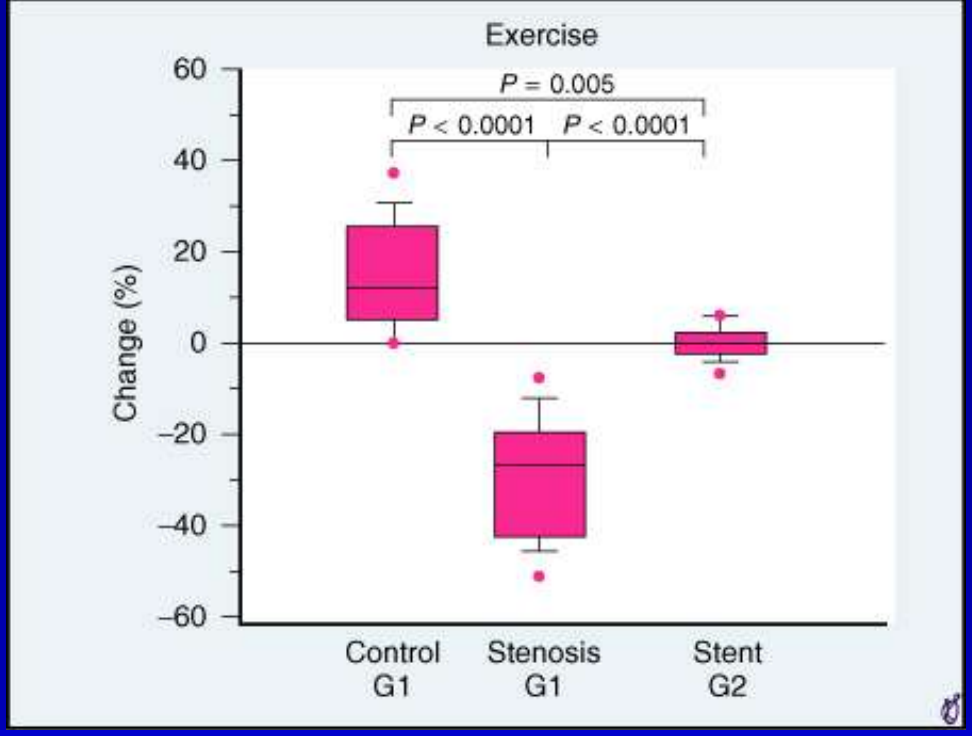
The resting electrocardiogram in this patient with coronary artery disease shows inferior and anterolateral T wave inversion, an adverse long-term prognosticator.

Transient conversion of a negative T wave at rest to a positive T wave during exercise is a nonspecific finding in patients without prior myocardial infarction and does not enhance the diagnostic or prognostic content of the test.

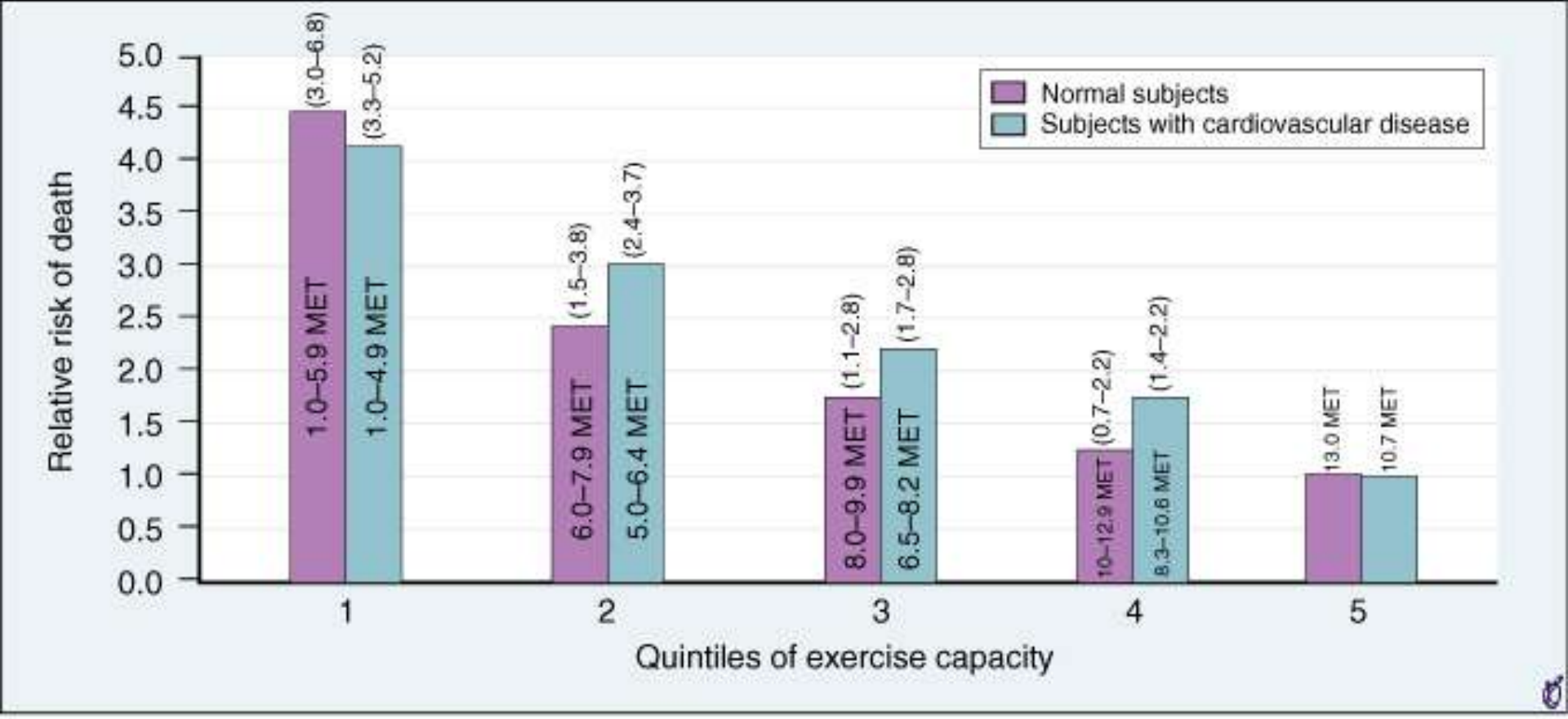
One more ECG issue

- Atrial repolarization may be a cause of false positive
- In an upright P wave, the PR segment is normally mildly depressed and is caused by the atrial repolarization
- During exercise, the P wave height increases and the atrial repolarization depth also increases, possibly causing false positive

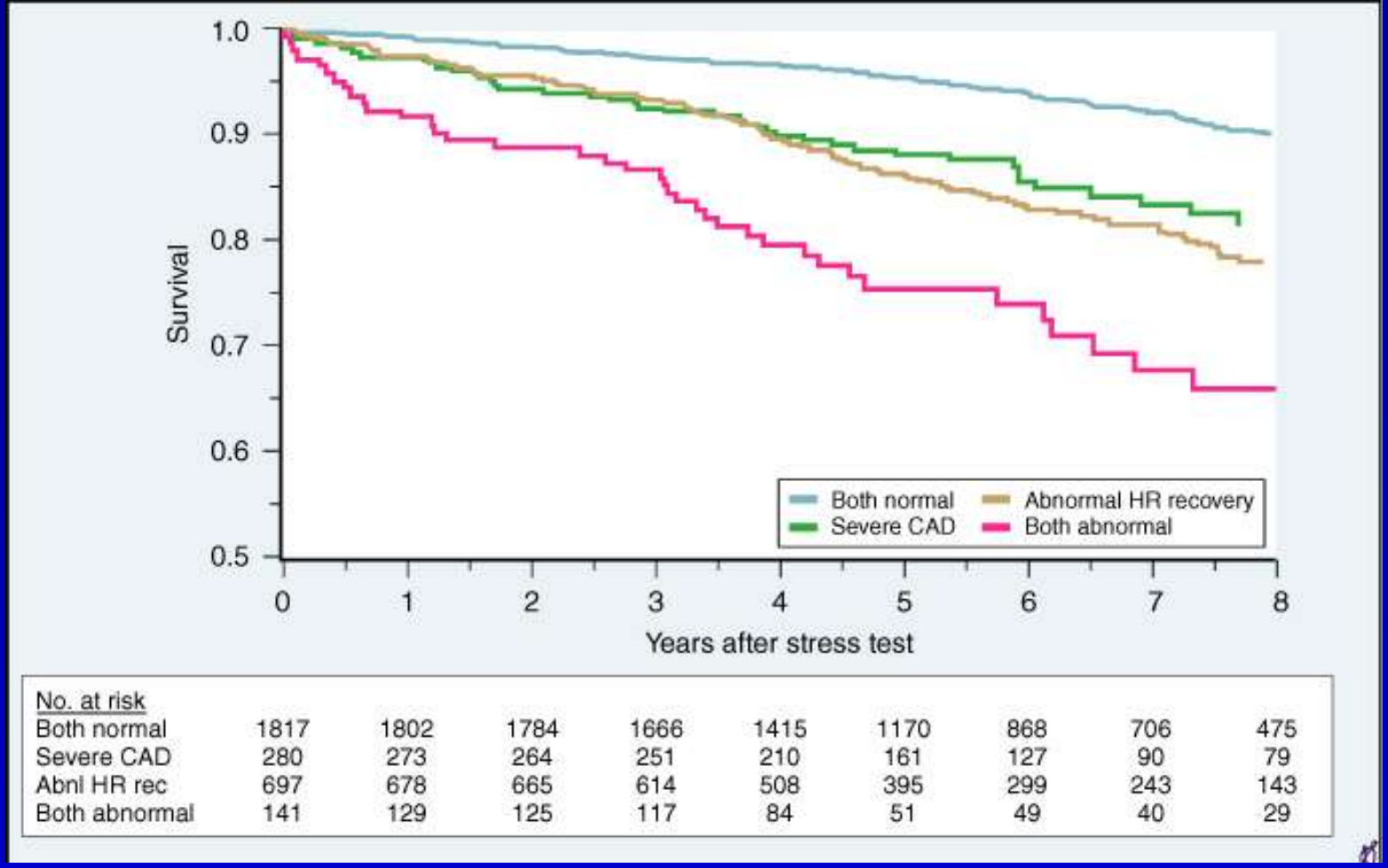
Atrial repolarization



Control group of 12 patients with chronic angina and single vessel disease (G1). 14 patients studied 10 months after coronary stenting (G2). In control group G1, the mean percentage diameter stenosis of the stenotic segment was 59 percent; during exercise, the stenotic segment exhibited coronary vasoconstriction (average − 29 percent compared with rest) compared with a control segment in the same vessel that showed vasodilation (+15 percent compared with rest). Sublingual nitroglycerin induced maximal vasodilation in the nonstenotic segment (+36 percent) and mild vasodilation (+10 percent) in the stenotic segments (not shown). Exercise does not elicit any vasomotion in stent group G2, and vessel diameter remains unchanged.

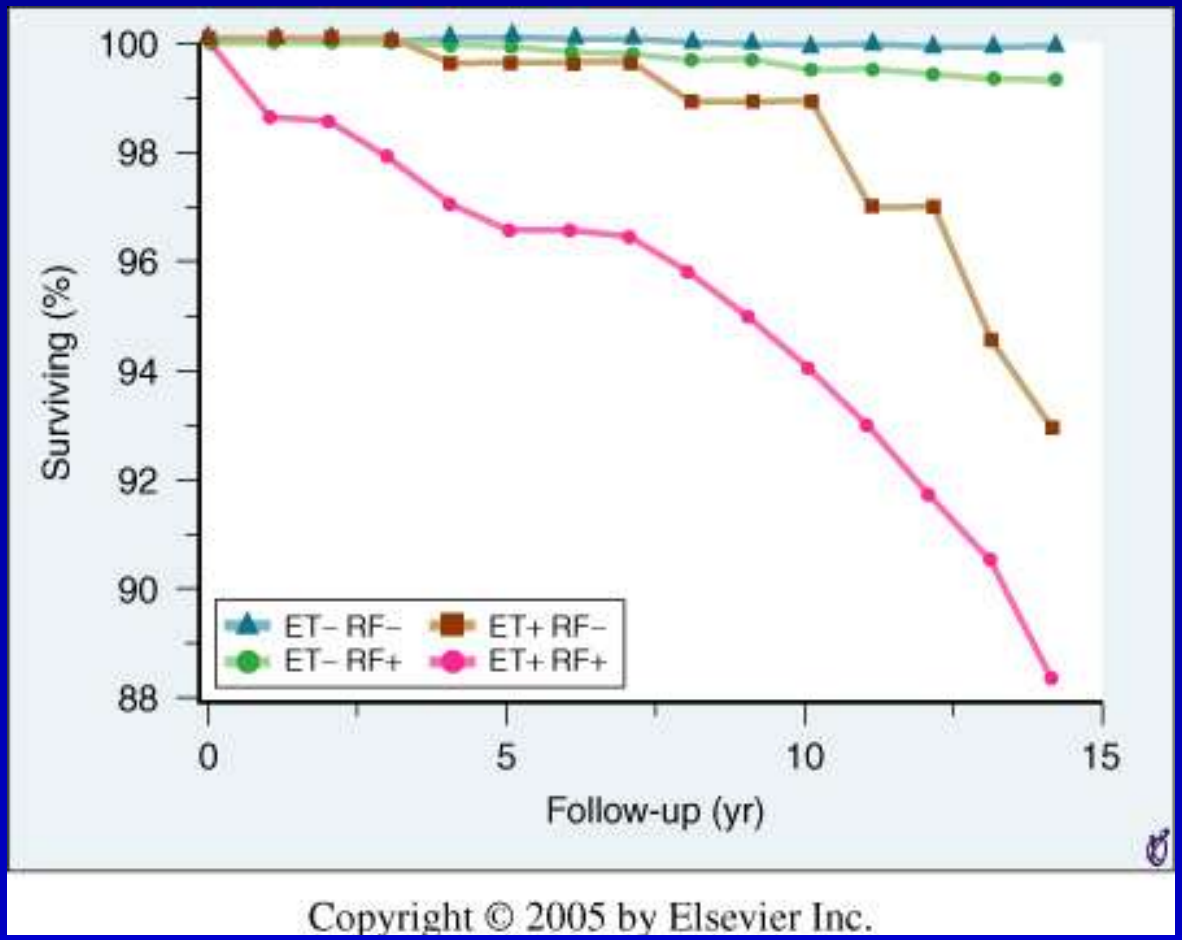


Age-adjusted relative risks of all-cause mortality by quintile of exercise capacity in 2534 subjects with a normal exercise test result and no history of cardiovascular disease and 3679 subjects with an abnormal exercise test result or history of cardiovascular disease. The mean duration of follow-up was 6.2 ± 3.7 years. Quintile 5 was used as the reference category. For each 1-MET increase in exercise capacity, the survival improved by 12 percent



No. at risk									
Both normal	1817	1802	1784	1666	1415	1170	868	706	475
Severe CAD	280	273	264	251	210	161	127	90	79
Abnl HR rec	697	678	665	614	508	395	299	243	143
Both abnormal	141	129	125	117	84	51	49	40	29

Six-year follow-up in 2935 patients who underwent an exercise test and coronary angiography. After adjustment for age, gender, standard risk factors, medications, exercise capacity, coronary disease extent, and left ventricular function, abnormal heart rate recovery (Abnl HR rec) was an independent predictor of mortality. The survival plot illustrates a mortality gradient with the worst prognosis in patients with abnormal heart rate recovery and severe coronary artery disease (CAD).



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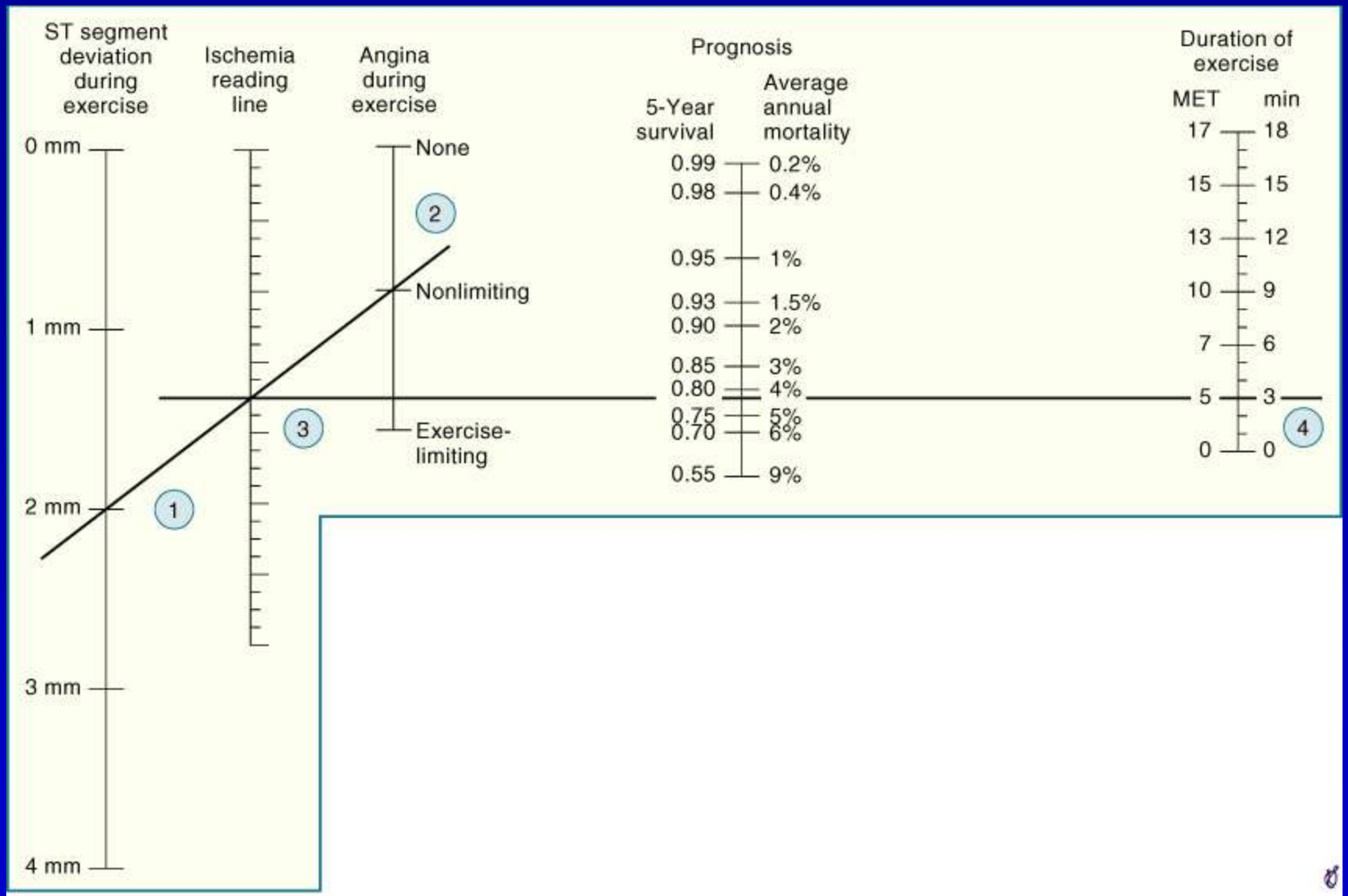
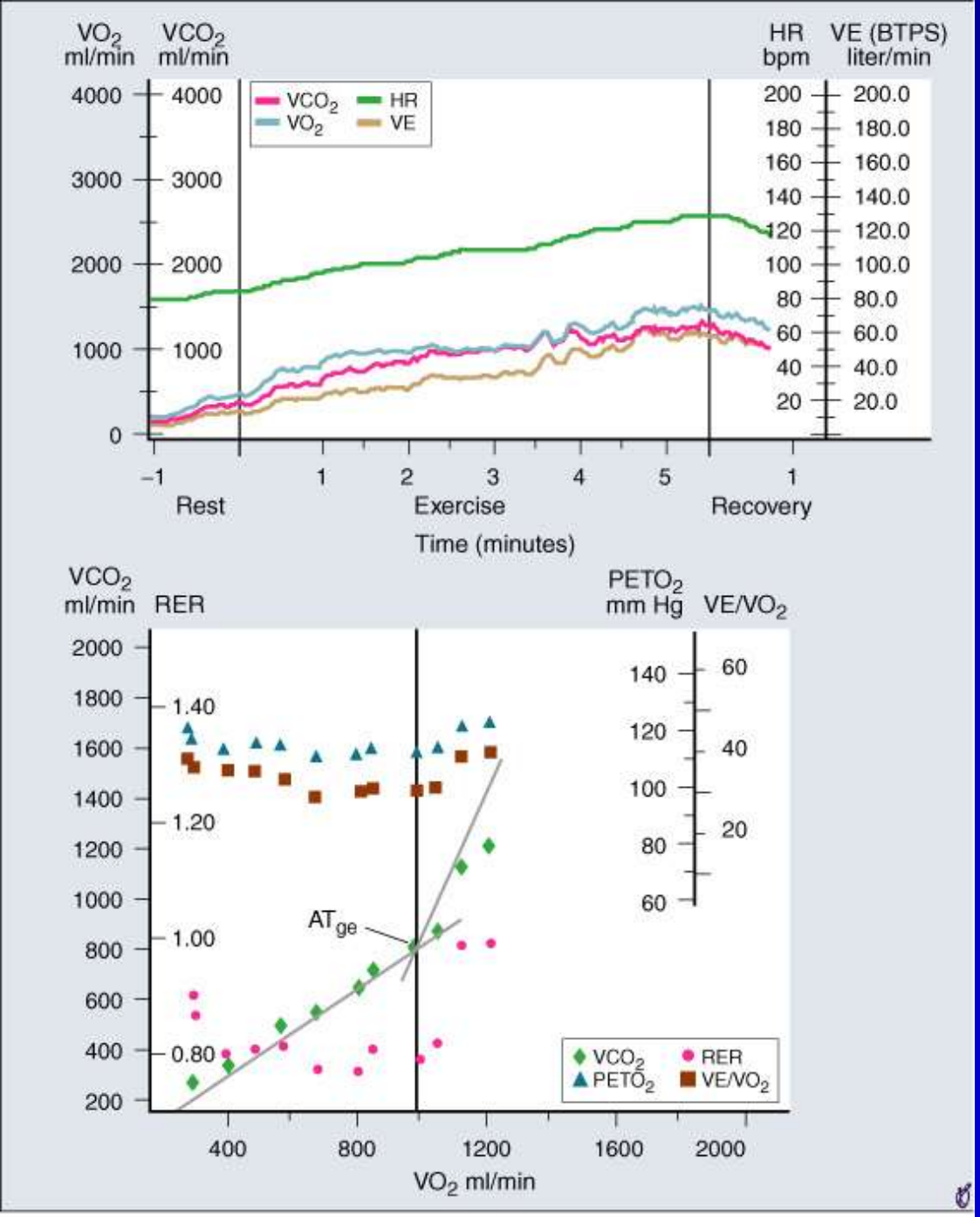
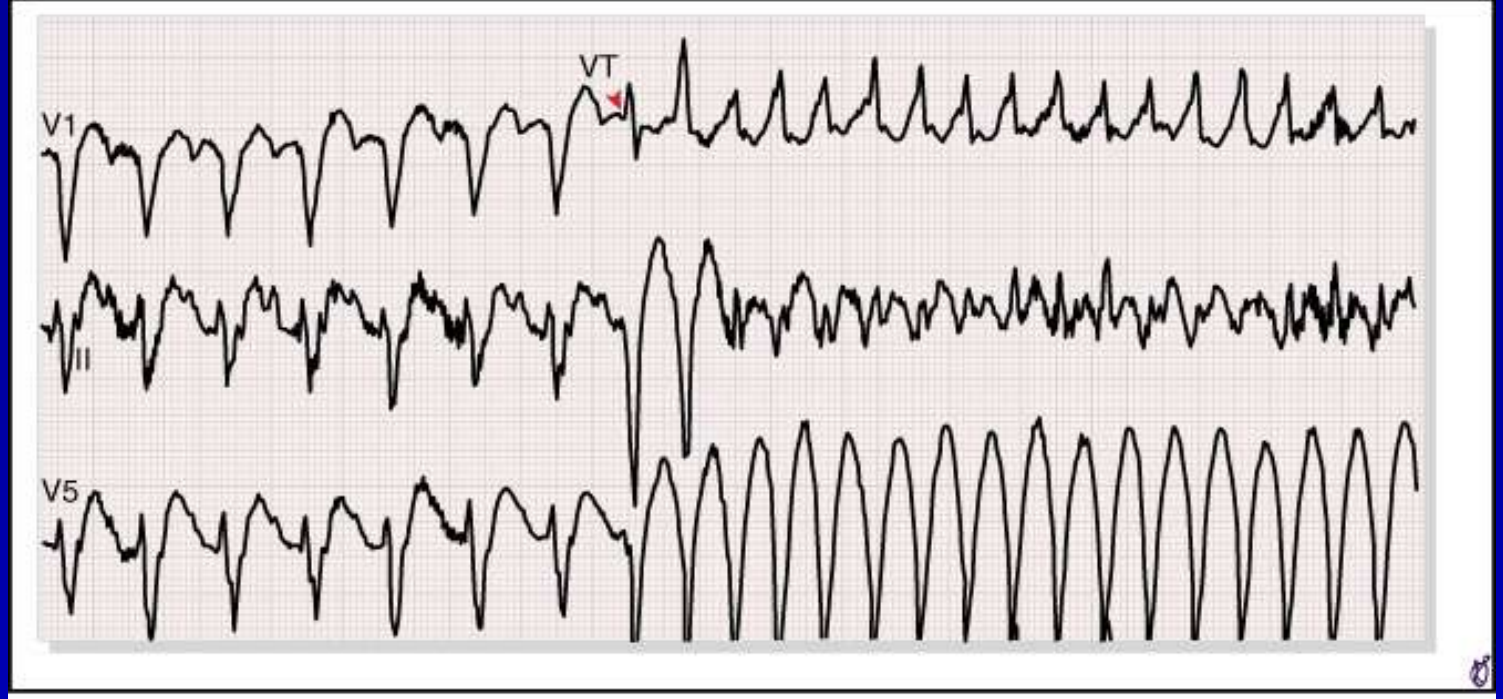
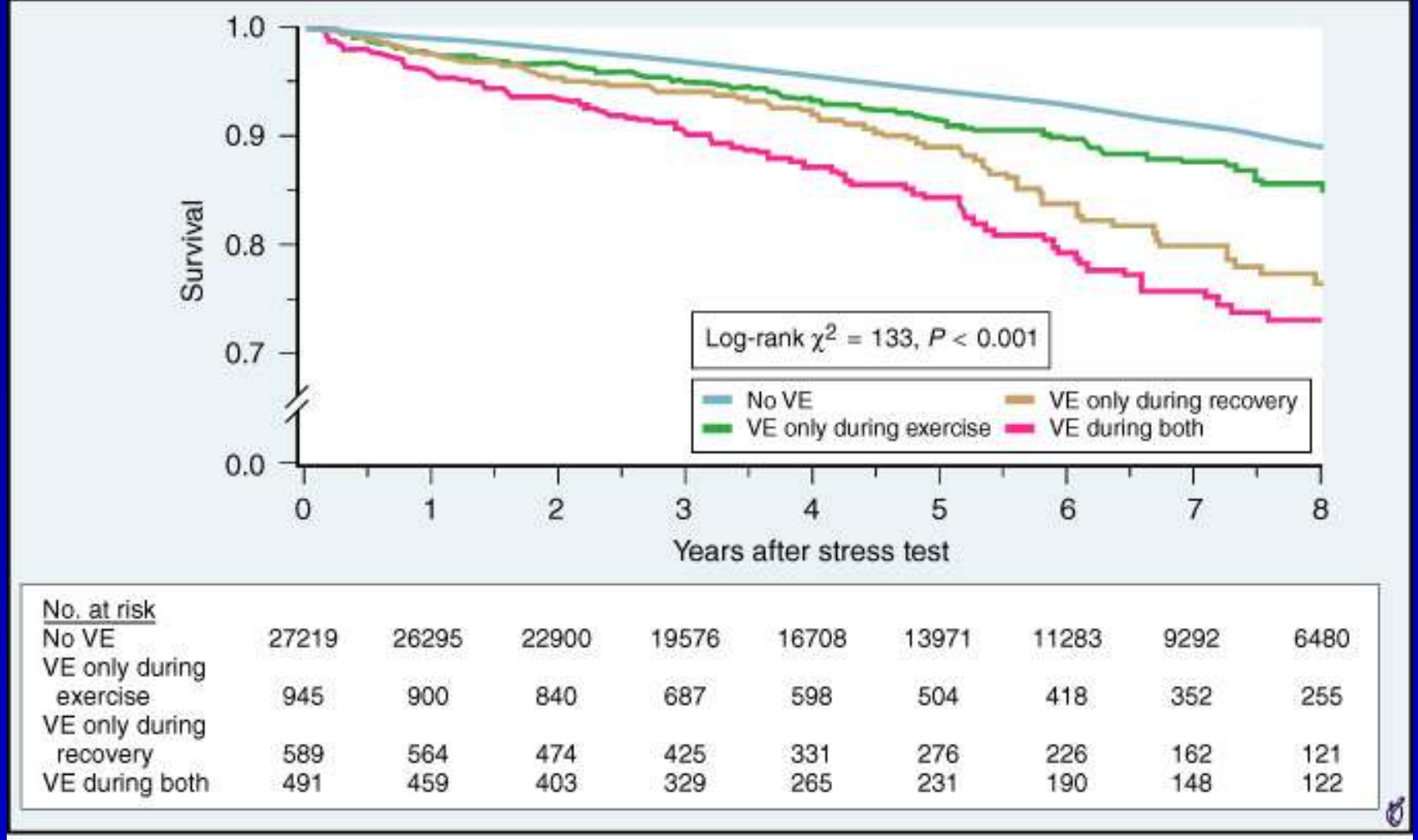




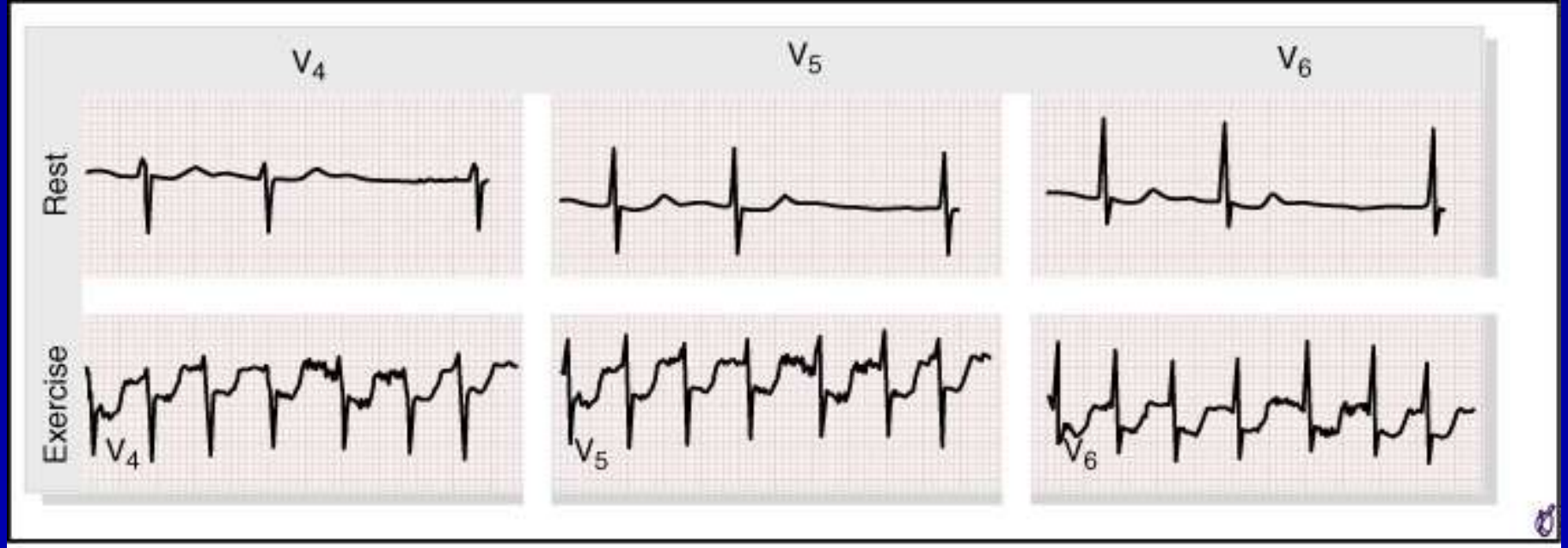
51-year-old man with cardiomyopathy in NYHA Class III. A modified Bruce protocol was used. The patient reached a peak O2 of 14ml O2/kg/min (4 METs), 44 percent of predicted for age, gender, and weight **(top).** Anaerobic threshold (ATge) occurred at a O2 of 977ml/min **(bottom).** The blunted cardiopulmonary response is typical for a patient with severe cardiomyopathy and marked impairment of cardiac reserve. This patient was listed for cardiac transplantation



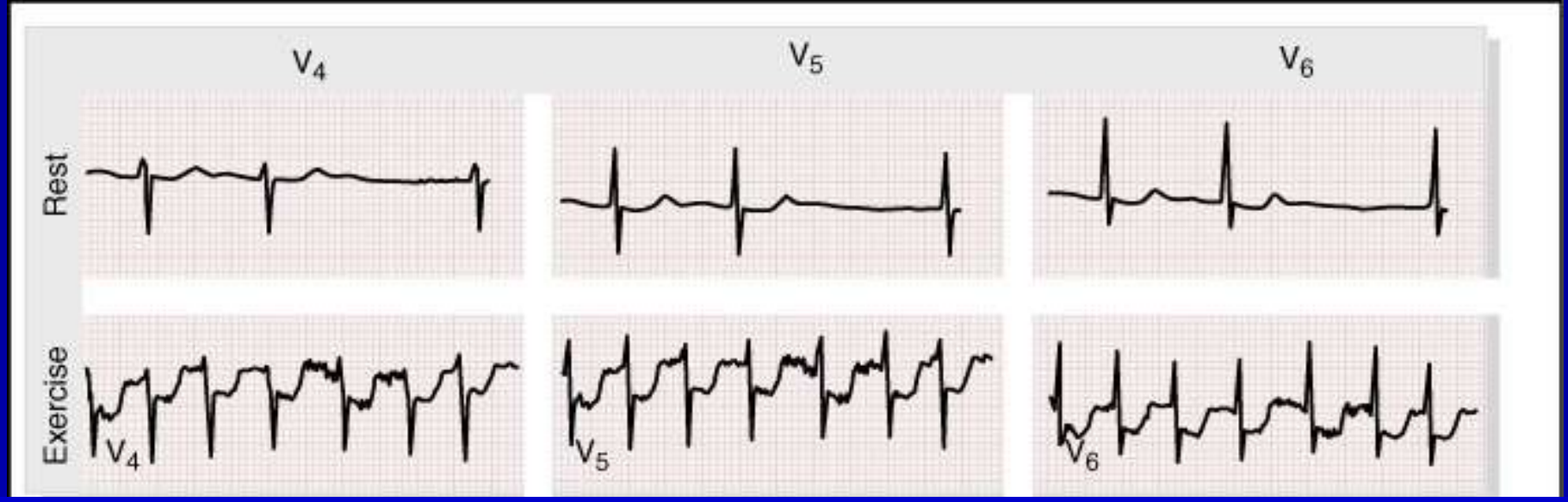


No. at risk									
No VE	27219	26295	22900	19576	16708	13971	11283	9292	6480
VE only during exercise	945	900	840	687	598	504	418	352	255
VE only during recovery	589	564	474	425	331	276	226	162	121
VE during both	491	459	403	329	265	231	190	148	122

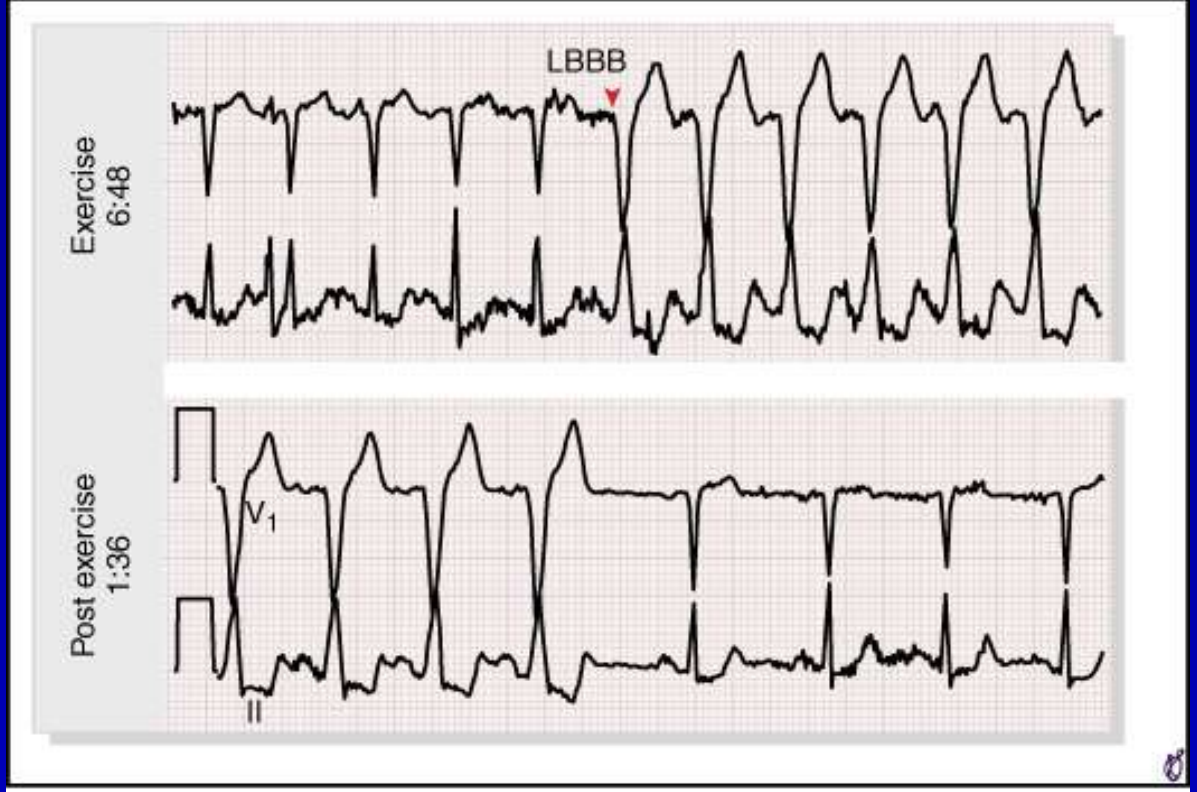
In this series of 29,244 subjects, frequent ventricular ectopy occurred in 3 percent of subjects only during exercise, in 2 percent of subjects only during recovery from exercise, and in 2 percent of subjects during both exercise and recovery. The prognosis of patients who had postexercise-induced frequent ventricular ectopy was worse than the prognosis of subjects who had frequent ventricular ectopy only during exercise. The mean follow-up time was 5.3 years.

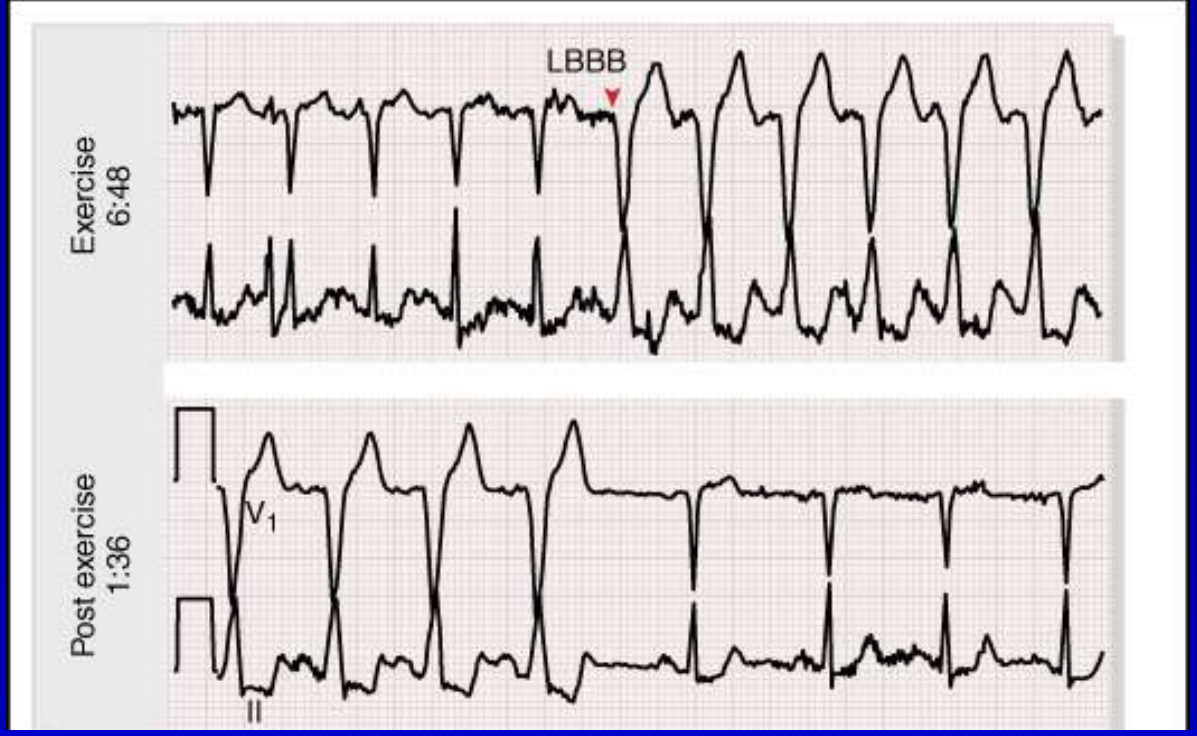


A 75-year-old woman with chronic AFib and atypical chest pain underwent mitral valve repair 1 year before testing, with nonobstructive coronary disease. The patient exercised for 6 minutes, achieving a peak HR of 176 beats/min and peak BP of 170/90 mm Hg. The resting ECG shows AFib with a controlled ventricular response and minor ST segment depression.

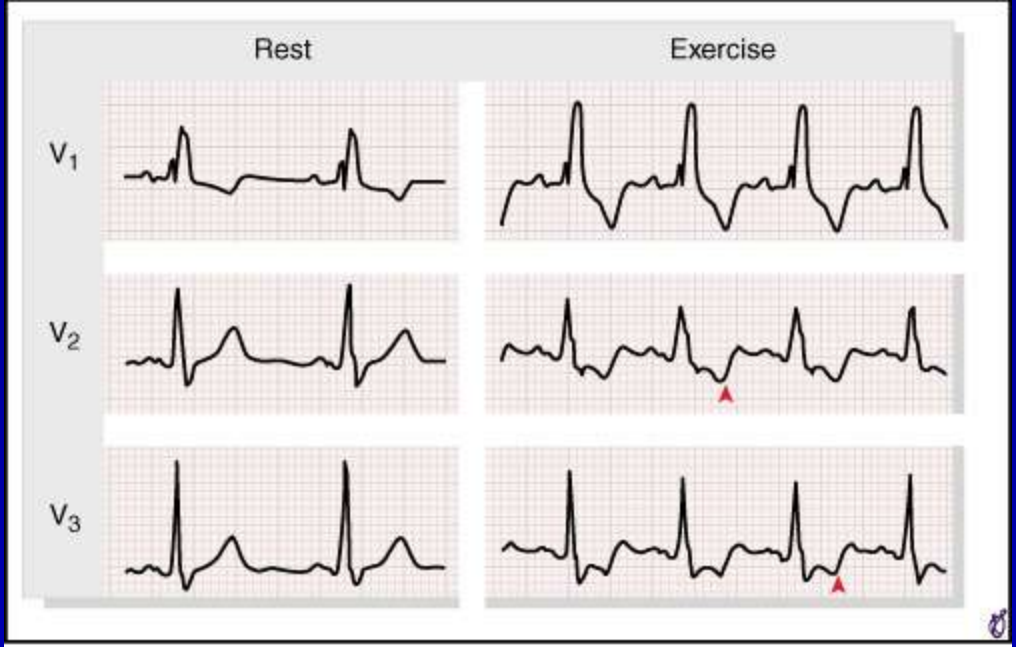


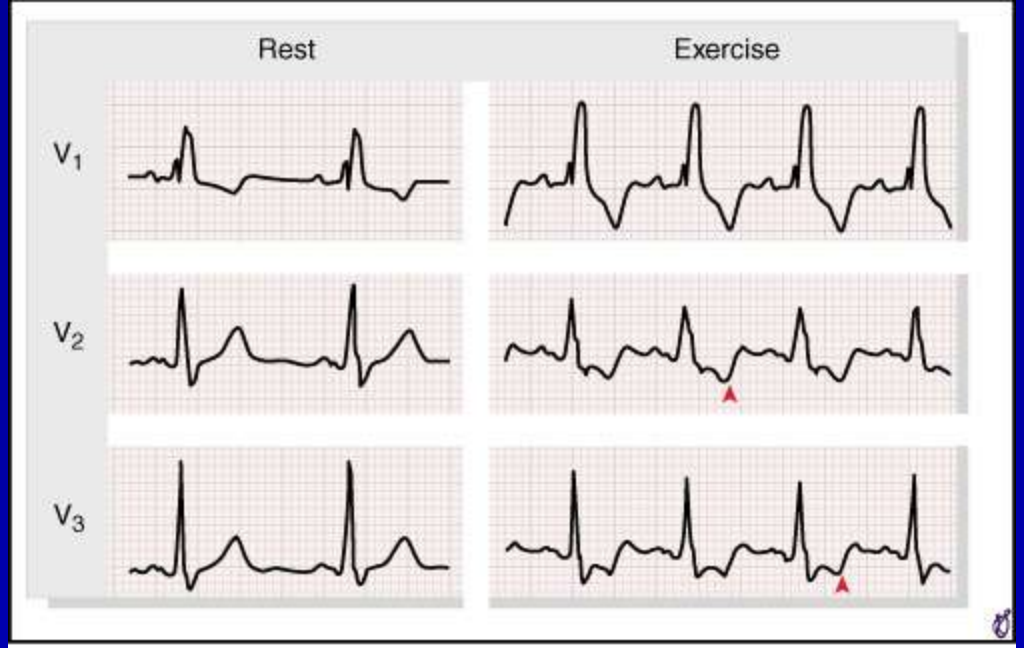
A 75-year-old woman with chronic AFib and atypical chest pain underwent mitral valve repair 1 year before testing, with nonobstructive coronary disease. The patient exercised for 6 minutes, achieving a peak HR of 176 beats/min and peak BP of 170/90 mm Hg. The resting ECG shows AFib with a controlled ventricular response and minor ST segment depression. At peak, marked ST depression is seen in the anterior leads, consistent with either digitalis effect or myocardial ischemia. In this type of patient, initial exercise testing with myocardial perfusion tracers or echocardiography would provide more useful diagnostic information than exercise testing alone.



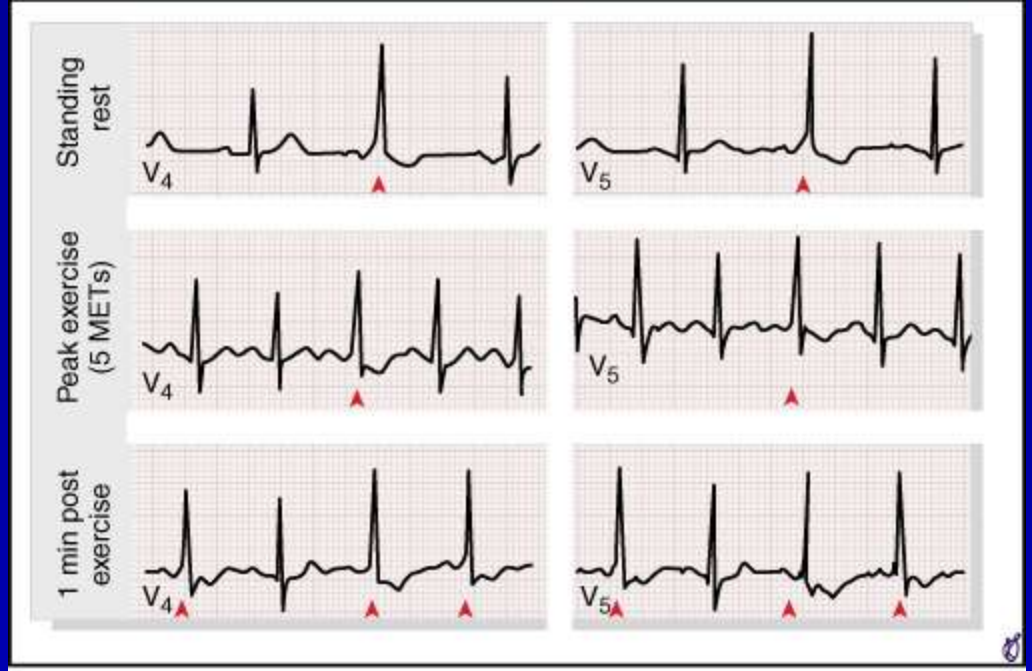


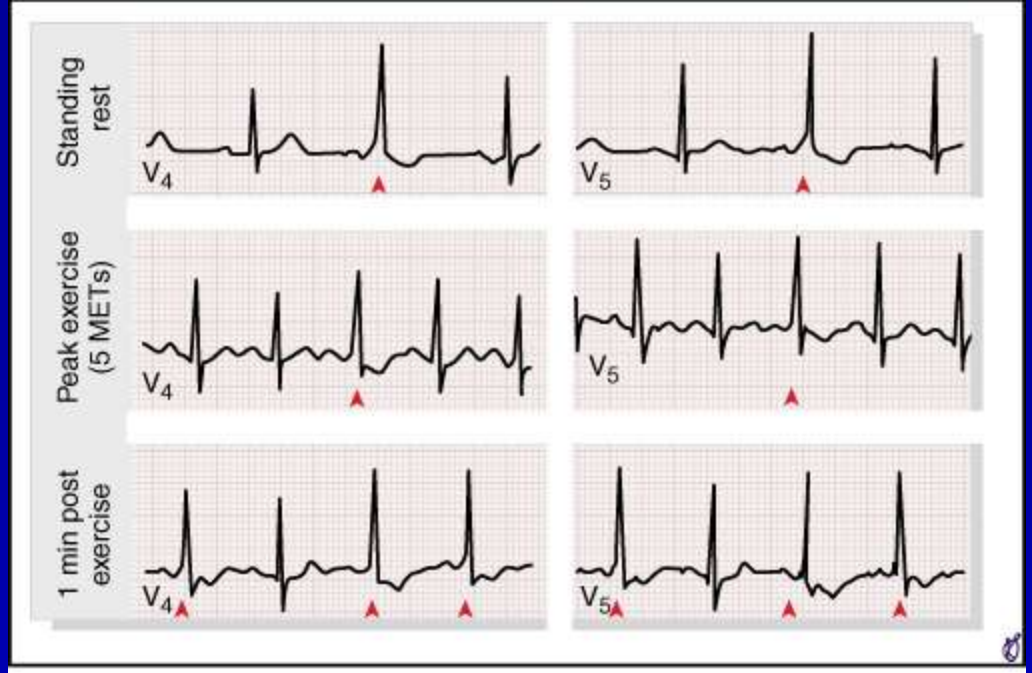
A 58-year-old man. DM, Htn, Smoking. Dyspnea and early fatigability during exercise. Rate-related left bundle branch block (LBBB) at a heart rate of 133 beats/min, which persisted during exercise and resolved at 1:36 minutes into the postexercise phase. The test was stopped because of dyspnea at a peak heart rate of 138 beats/min (85 percent of predicted) and estimated workload of 6 METs. Peak BP was 174/94 mm Hg. Time to onset and offset of LBBB occurred at different ventricular rates related to fatigue in the left bundle, a common finding.



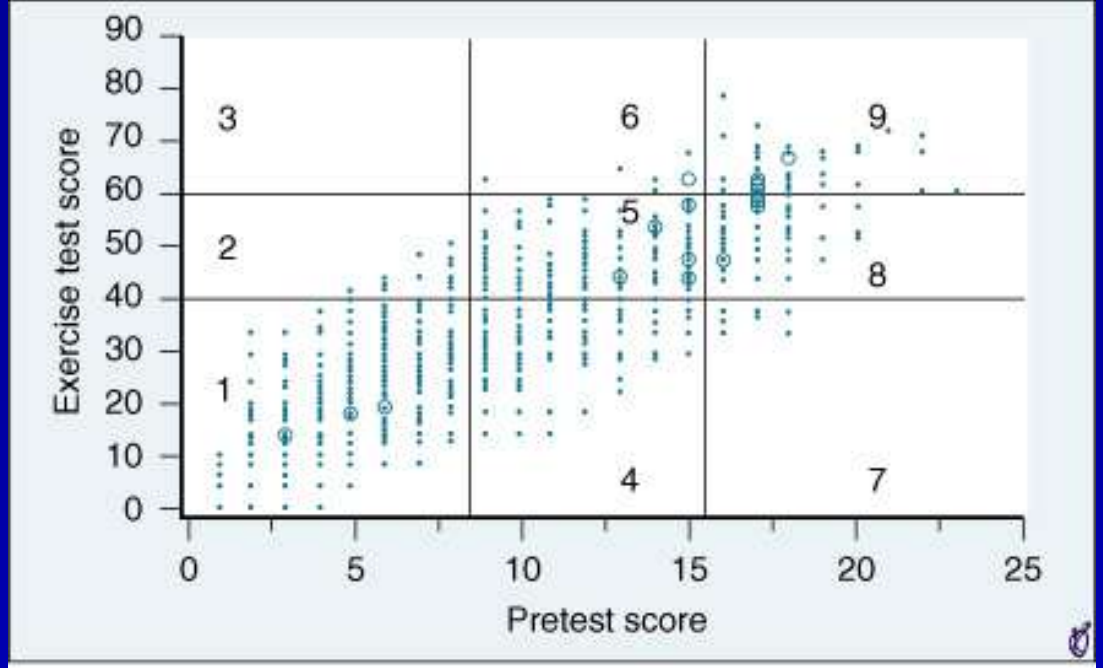


Exercise-induced ST segment depression is noted in leads V2 to V3 (arrows) in this patient with a resting right bundle branch block (RBBB) pattern. Exercise-induced horizontal or downsloping ST segment responses in the early anterior precordial leads (V1 through V4) are common in patients with RBBB and are secondary to the conduction disturbance. The presence of this finding in leads V1 through V4 is not diagnostic of obstructive coronary disease; however, if ischemic changes are seen in leads II, aVF, or in leads V5 or V6, the specificity for coronary disease is improved.

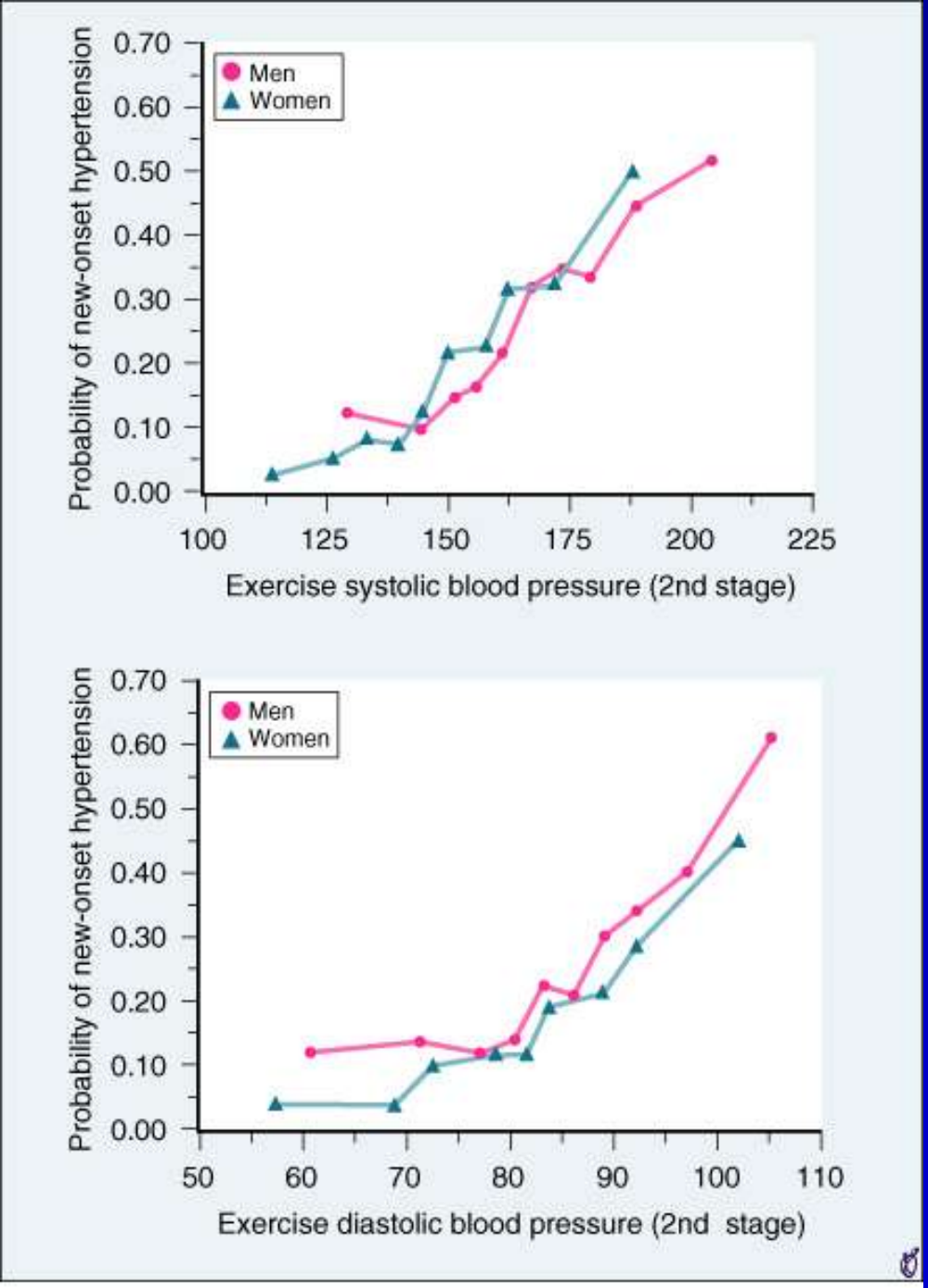




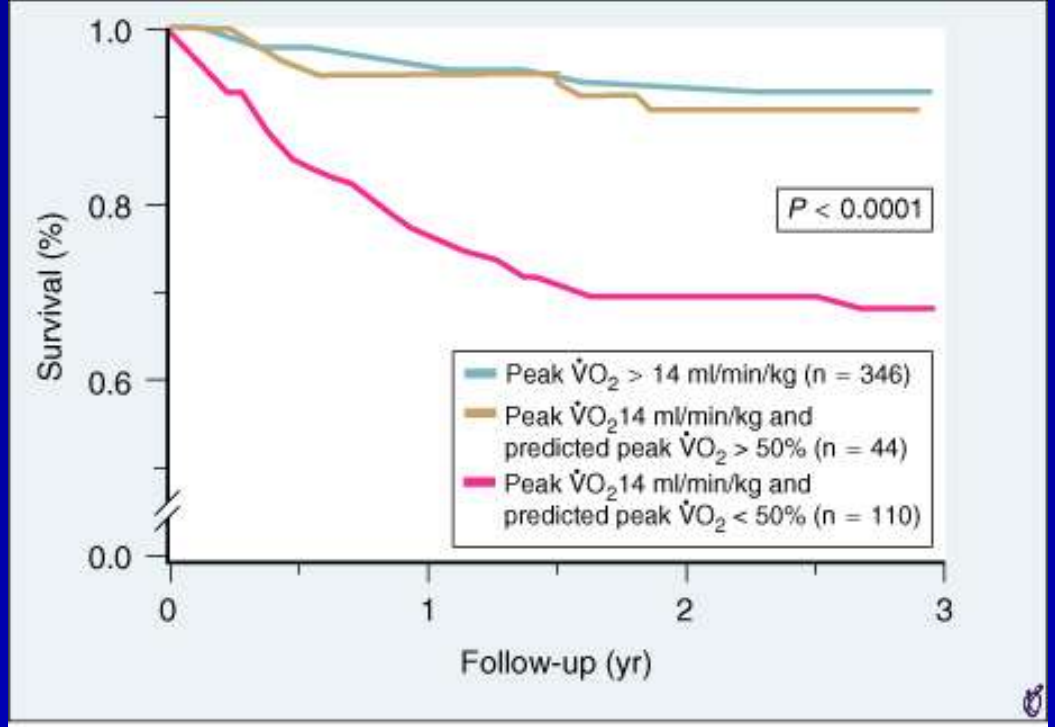
61-year-old man with atypical angina and a hiatal hernia was referred for diagnostic exercise testing. The test was stopped because of dyspnea. The standing resting ECG shows an intermittent Wolff-Parkinson-White pattern (arrows). In the nonpreexcited beats, ST segment depression does not occur either at peak exercise or in the postexercise phase. However, in the preexcited beats (arrows), an additional 1.3 mm of downsloping ST segment depression is noted as compared with baseline during and after exertion.



Scatter plot of exercise score as a function of pretest score for 1678 women referred for exercise testing. Points for those alive (closed circles) and dead (open circles) are shown. Heavy gridlines represent cutpoints for low-intermediate and intermediate-high risk groups for each score. Lowest risk patients (lowest pretest risk and lowest exercise score) are in sector 1 and highest risk patients (highest pretest risk and highest exercise score) in sector 9. Mortality after a mean 2.6-year follow-up was greatest in women with at least an intermediate pretest clinical score and exercise test score. Clinical variables include age, symptoms, diabetes, smoking, and estrogen status. Exercise ECG score variables include ST depression, peak heart rate, and Duke angina index.



Probability of developing systemic hypertension within 8 years after exercise testing as a function of exercise-induced systolic **(top)** and diastolic **(bottom)** blood pressure responses in men and women. Crude probabilities of developing hypertension are displayed for mean systolic or diastolic blood pressure value for each exercise response during the second stage of treadmill testing.



The 3-year survival of patients with congestive heart failure referred for cardiac transplant evaluation with a peak O2 of 14ml O2/kg/min or less stratified according to predicted peak O2 greater than 50 percent or less. The 91 ±5 percent 3-year survival rate of the 44 patients with a predicted O2 greater than 50 percent was similar to the survival rates of patients with a peak O2 greater than 14 ml O2/kg/min and significantly greater than the 61 ±5 percent survival rate of the 110 patients with a peak O2 of 50 percent or less. The data indicate that a low peak O2 and percentage predicted O2 identify high-risk patients with congestive heart failure whose survival may be improved by cardiac transplantation.

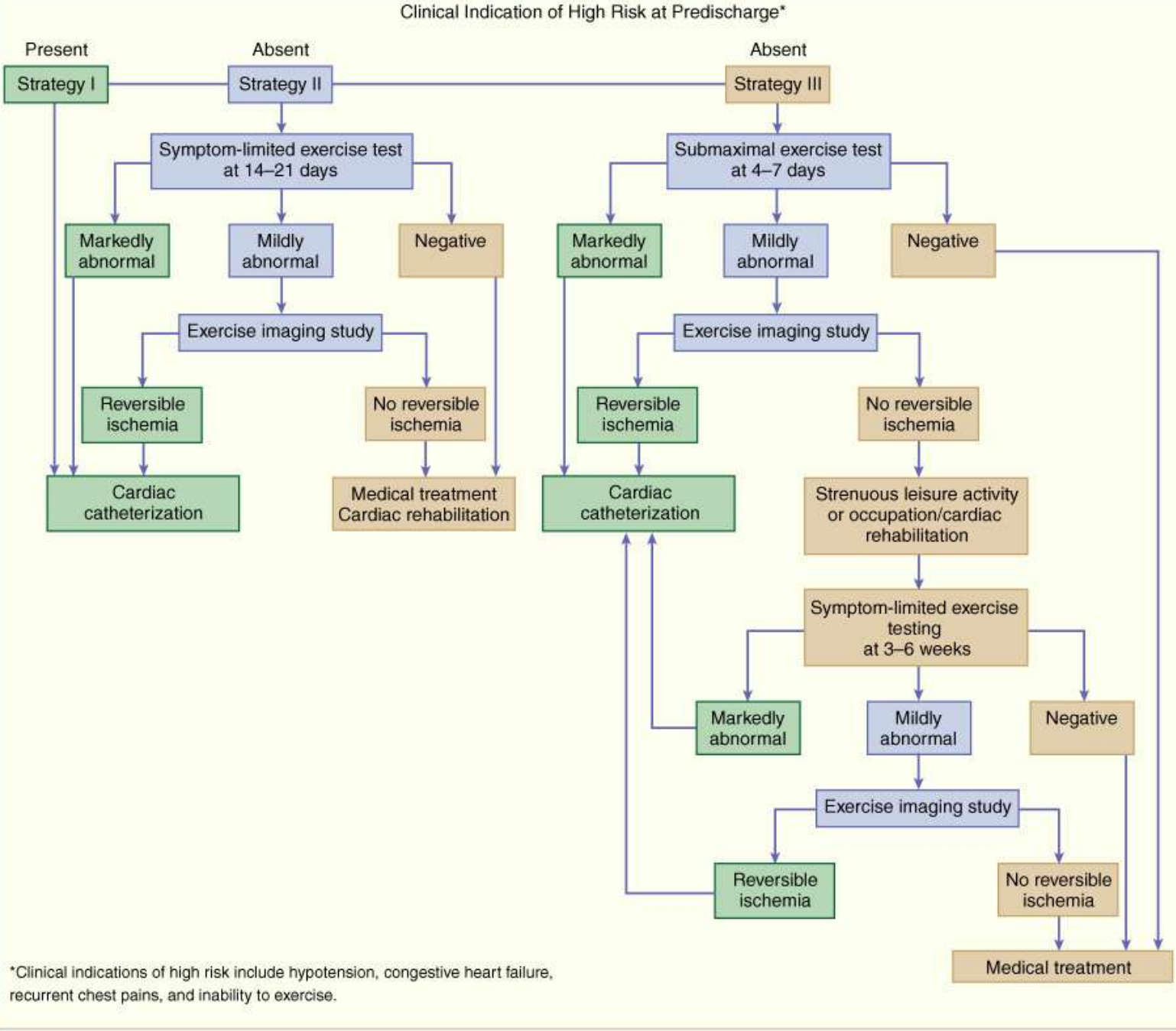


TABLE 10–1 Terms Useful in Evaluation of Test Results

Term	Definition
True positive (TP)	Abnormal test result in individual with disease
False positive (FP)	Abnormal test result in individual without disease
True negative (TN)	Normal test result in individual without disease
False negative (FN)	Normal test result in individual with disease
Sensitivity	Percentage of patients with CAD who have an abnormal result = TP/(TP + FN)
Specificity	Percentage of patients without CAD who have a normal result = TN/(TN + FP)
Predictive value	Percentage of patients with an abnormal result who have CAD = TN/(TN + FN)
Test accuracy	Percentage of true test results = (TP + TN)/total number tests performed
Likelihood ratio	Odds of a test result being true abnormal test result: sensitivity/(1 – specificity) normal test result: specificity/(1 – sensitivity)
Relative risk	Disease rate in persons with a positive test result/disease rate in persons with a negative test result

CAD = coronary artery disease.

TABLE 10–2 Noncoronary Causes of ST Segment Depression	
Severe aortic stenosis	Glucose load
Severe hypertension	Left ventricular hypertrophy
Cardiomyopathy	Hyperventilation
Anemia	Mitral valve prolapse
Hypokalemia	Intraventricular conduction disturbance
Severe hypoxia	Preexcitation syndrome
Digitalis use	Severe volume overload (aortic, mitral regurgitation)
Sudden excessive exercise	Supraventricular tachyarrhythmias

TABLE 10–3	Exercise Parameters Associated with an Adverse Prognosis and Multivessel Coronary Artery Disease
Duration of symptom-limiting exercise < 5 METs	
Failure to increase systolic blood pressure ≥ 120 mm Hg, or a sustained decrease ≥ 10 mm Hg, or below rest levels, during progressive exercise	
ST segment depression ≥ 2 mm, downsloping ST segment, starting at <5 METs, involving ≥5 leads, persisting ≥5 min into recovery	
Exercise-induced ST segment elevation (aV excluded)	
Angina pectoris at low exercise workloads	
Reproducible sustained (>30 sec) or symptomatic ventricular tachycardia	
Acute systemic illness (pulmonary embolism, aortic dissection)	

TABLE 10–4	Absolute Contraindications to Exercise Testing
Acute myocardial infarction (<2 d)	
High-risk unstable angina	
Decompensated heart failure	
Uncontrolled cardiac arrhythmias with symptoms or hemodynamic compromise	
Advanced atrioventricular block	
Acute myocarditis or pericarditis	
Severe symptomatic aortic stenosis	
Severe hypertrophic obstructive cardiomyopathy	
Uncontrolled hypertension	
Acute systemic illness (pulmonary embolism, aortic dissection)	

TABLE 10–5 Indications for Terminating Exercise Testing

Absolute indications
Drop in systolic blood pressure of >10 mm Hg from baseline blood pressure despite an increase in workload, when accompanied by other evidence of ischemia
Moderate to severe angina (grade 3/4)
Increasing nervous system symptoms (e.g., ataxia, dizziness, or near-syncope)
Signs of poor perfusion (cyanosis or pallor)
Technical difficulties in monitoring ECG or systolic blood pressure
Subject's desire to stop
Sustained ventricular tachycardia
ST elevation (≥1.0 mm) in noninfarct leads without diagnostic Q waves (other than V_1 or aV)
Relative indications
Drop in systolic blood pressure of ≥10 mm Hg from baseline blood pressure despite an increase in workload, in the absence of other evidence of ischemia
ST or QRS changes such as excessive ST depression (>3 mm of horizontal or downsloping ST segment depression) or marked axis shift
Arrhythmias other than sustained ventricular tachycardia, including multifocal PVCs, triplets of PVCs, supraventricular tachycardia, heart block, or bradyarrhythmias
Fatigue, shortness of breath, wheezing, leg cramps, or claudication
Development of bundle branch block of intraventricular conduction delay that cannot be distinguished from ventricular tachyardia
Increasing chest pain
Hypertensive response

ECG = electrocardiogram; PVCs = premature ventricular contractions.

Modified from Fletcher GF: Exercise standards: A standard for healthcare professionals from the American Heart Association Writing Group. Circulation 91:580, 1995.

TABLE 10–6 Exercise Test Report Information
Demographic data: name, patient identifier, date of birth/age, gender, weight, height, test date
Indication(s) for test
Patient descriptors: atherosclerotic risk profile, drug usage, resting ECG findings
Exercise test results
Protocol used
Reason(s) for stopping exercise
Hemodynamic data: rest and peak heart rate, rest and peak blood pressure, percent maximum achieved heart rate, maximum rate of perceived exertion (Borg scale), peak workload, peak METs, total exercise duration in minutes
Evidence for myocardial ischemia: time to onset and offset of ischemic ST segment deviation or angina, maximum depth of ST segment deviation, number of abnormal exercise ECG leads, abnormal systemic blood pressure responses
General comments

ECG = electrocardiogram; METs = metabolic equivalents.

TABLE 10G–1	ACC/AHA Guidelines: Absolute and Relative Contraindications to Exercise Testing
Absolute	
Acute myocardial infarction (within 2 days)	
High-risk unstable angina	
Uncontrolled cardiac arrhythmias causing symptoms or hemodynamic compromise	
Symptomatic severe aortic stenosis	
Uncontrolled symptomatic heart failure	
Acute pulmonary embolus or pulmonary infarction	
Acute myocarditis or pericarditis	
Acute aortic dissection	
Relative	
Left main coronary stenosis	
Moderate stenotic valvular heart disease	
Electrolyte abnormalities	
Severe arterial hypertension (suggested definition: systolic blood pressure > 200 mm Hg and/or diastolic blood pressure > 100 mm Hg)	
Tachyarrhythmias or bradyarrhythmias	
Hypertrophic cardiomyopathy and other forms of outflow tract obstruction	
Mental or physical impairment leading to inability to exercise adequately	
High-degree atrioventricular block	

From Gibbons RJ, Balady GJ, Bricker JT, et al: ACC/AHA 2002 guideline update for exercise testing: Summary article. A report of the ACC/AHA Task Force on Practice Guidelines (Committee to update the 1997 Exercise Testing Guidelines). Circulation 106:1883, 2002.

TABLE 10G–2 ACC/AHA Guidelines: Indications for Terminating Exercise Testing

Absolute
Drop in systolic blood pressure of >10 mm Hg from baseline blood pressure despite an increase in workload, when accompanied by other evidence of ischemia
Moderate to severe angina
Increasing nervous system symptoms (e.g., ataxia, dizziness, or near-syncope)
Signs of poor perfusion (cyanosis or pallor)
Technical difficulties in monitoring electrocardiogram or systolic blood pressure
Subject's desire to stop
Sustained ventricular tachycardia
ST elevation (≥1.0 mm) in leads without diagnostic Q waves (other than V_1 or aV_R)
Relative
Drop in systolic blood pressure of >10 mm Hg from baseline blood pressure despite an increase in workload, in the absence of other evidence of ischemia
ST or QRS changes such as excessive ST depression (>2 mm of horizontal or downsloping ST segment depression) or marked axis shift
Arrhythmias other than sustained ventricular tachycardia, including multifocal PVCs, triplets of PVCs, supraventricular tachycardia, heart block, or bradyarrhythmias
Fatigue, shortness of breath, wheezing, leg cramps, or claudication
Development of bundle-branch block or IVCD that cannot be distinguished from ventricular tachycardia
Increasing chest pain
Hypertensive response (suggested definition: systolic blood pressure > 250 mm Hg and/or a diastolic blood pressure of > 115 mm Hg)

ECG = electrocardiogram; ICD = implantable cardioverter-defibrillator discharge; IVCD = intraventricular conduction delay; PVCs = premature ventricular contractions.

From Gibbons RJ, Balady GJ, Bricker JT, et al: ACC/AHA 2002 guideline update for exercise testing: Summary article. A report of the ACC/AHA Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). Circulation 106:1883, 2002.

TABLE 10G–3 Pretest Probability of Coronary Artery Disease by Age, Gender and Symptoms

Age (yr)	Gender	Typical/Definite Angina Pectoris	Atypical/Probable Angina Pectoris	Nonanginal Chest Pain	Asymptomatic
30–39	Men	Intermediate	Intermediate	Low	Very low
	Women	Intermediate	Very low	Very low	Very low
40–49	Men	High	Intermediate	Intermediate	Low
	Women	Intermediate	Low	Very low	Very low
50–59	Men	High	Intermediate	Intermediate	Low
	Women	Intermediate	Intermediate	Low	Very low
60–69	Men	High	Intermediate	Intermediate	Low
	Women	High	Intermediate	Intermediate	Low

From Gibbons RJ, Balady GJ, Bricker JT, et al: ACC/AHA 2002 guideline update for exercise testing: Summary article. A report of the ACC/AHA Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). Circulation 106:1883, 2002.

TABLE 10G–4 ACC/AHA Guidelines for Exercise Testing to Diagnose Obstructive Coronary Artery Disease

	Indication
Class I (indicated)	Adult patients (including those with complete right bundle branch block or less than 1 mm of resting ST depression) with an intermediate pretest probability of CAD on the basis of gender, age, and symptoms (specific exceptions are noted under Classes II and III below).
Class IIa (good supportive evidence)	Patients with vasospastic angina.
Class IIb (weak supportive evidence)	1. Patients with a high pretest probability of CAD by age, symptoms, and gender. 2. Patients with a low pretest probability of CAD by age, symptoms, and gender. 3. Patients with less than 1 mm of baseline ST depression and taking digoxin. 4. Patients with electrocardiographic criteria for left ventricular hypertrophy and less than 1 mm of baseline ST depression.
Class III (not indicated)	1. Patients with the following baseline ECG abnormalities: • Preexcitation (Wolff-Parkinson-White) syndrome • Electronically paced ventricular rhythm • Greater than 1 mm of resting ST depression • Complete left bundle branch block 2. Patients with a documented myocardial infarction or prior coronary angiography demonstrating significant disease who have an established diagnosis of CAD; however, ischemia and risk can be determined by testing.

CAD = coronary artery disease.

TABLE 10G–5 ACC/AHA Guidelines: Risk Assessment and Prognosis in Patients with Symptoms or a Prior History of Coronary Artery Disease

	Indication
Class I (indicated)	1. Patients undergoing initial evaluation with suspected or known CAD, including those with complete right bundle branch block or less than 1 mm of resting ST depression. Specific exceptions are noted below in Class IIb. 2. Patients with suspected or known CAD, previously evaluated, now presenting with significant change in clinical status. 3. Low-risk unstable angina patients 8 to 12 hours after presentation who have been free of active ischemic or heart failure symptoms. 4. Intermediate-risk unstable angina patients 2 to 3 days after presentation who have been free of active ischemic or heart failure symptoms.
Class IIa (good supportive evidence)	Intermediate-risk unstable angina patients who have initial cardiac markers that are normal, a repeat ECG without significant change, and cardiac markers 6 to 12 hours after the onset of symptoms that are normal and no other evidence of ischemia during observation.
Class IIb (weak supportive evidence)	1. Patients with the following resting ECG abnormalities: • Preexcitation (Wolff-Parkinson-White) syndrome • Electronically paced ventricular rhythm • 1 mm or more of resting ST depression • Complete left bundle branch block or any interventricular conduction defect with a QRS duration longer than 120 msec. 2. Patients with a stable clinical course who undergo periodic monitoring to guide treatment.
Class III (not indicated)	1. Patients with severe comorbidity likely to limit life expectancy and/or candidacy for revascularization. 2. High-risk unstable angina patients.

CAD = coronary artery disease; ECG = electrocardiogram.

TABLE 10G–6 ACC/AHA Classification System for Risk of Death or Nonfatal Myocardial Infarction in Patients with Unstable Angina

Feature	High Risk (at least one of the following features must be present)	Intermediate Risk (no high-risk feature but must have one of the following features)	Low Risk (no high- or intermediate-risk features, but may have any of the following features)
History		Prior MI, peripheral or cerbrovascular disease, or CABG, prior aspirin use	
Character of pain	Prolonged, ongoing (>20 min) pain at rest	Prolonged (>20 min) resting angina, now resolved, with moderate or high likelihood of CAD Rest angina (<20 min) or relieved with rest or sublingual NTG	New-onset or progressive CCSC III or IV angina in the past 2 weeks with moderate or high likelihood of CAD
Clinical findings	Pulmonary edema, most likely related to ischemia New or worsening MR murmur S3 or new/worsening rales Hypotension, bradycardia, tachycardia Age older than 75 years	Age older than 70 yr	
ECG findings	Angina at rest with transient ST changes ≥ 0.05 mV BBB, new or presumed new/sustained ventricular tachycardia	T-wave inversions greater than 0.2 mV Pathological Q waves	Normal or unchanged ECG during an episode of chest discomfort
Biochemical cardiac markers	Elevated (e.g., troponin T or I greater than 0.1 mg/ml)	Slightly elevated (e.g., troponin T > 0.01 but <0.1 mg/ml)	Normal

BBB = bundle branch block; CABG = coronary artery bypass graft; CAD = coronary artery disease; CCSC = Canadian Cardiovascular Society Classification; ECG = electrocardiogram; MI = myocardial infarction; MR = mitral regurgitation.

From Gibbons RJ, Balady GJ, Bricker JT, et al: ACC/AHA 2002 guideline update for exercise testing: Summary article. A report of the ACC/AHA Task Force on Practice Guidelines (Committee to update the 1997 Exercise Testing Guidelines). Circulation 106:1883, 2002.

TABLE 10G–7 ACC/AHA Guidelines for Exercise Testing after Acute Myocardial Infarction

	Indication
Class I (indicated)	1. Before discharge for prognostic assessment, activity prescription, evaluation of medical therapy (submaximal at about 4 to 76 days).* 2. Early after discharge for prognostic assessment, activity prescription, evaluation of medical therapy, and cardiac rehabilitation if the predischarge exercise test was not done (symptom-limited; about 14 to 21 days).* 3. Late after discharge for prognostic assessment, activity prescription, evaluation of medical therapy, and cardiac rehabilitation if the early exercise test was submaximal (symptom-limited; about 3 to 6 weeks).*
Class IIa (good supportive evidence)	After discharge for activity counseling and/or exercise training as part of cardiac rehabilitation in patients who have undergone coronary revascularization.
Class IIb (weak supportive evidence)	1. Patients with the following electrocardiographic abnormalities: • Complete left bundle-branch block • Preexcitation syndrome • Left ventricular hypertrophy • Digoxin therapy • Greater than 1 mm of resting ST segment depression • Electronically paced ventricular rhythm 2. Periodic monitoring in patients who continue to participate in exercise training or cardiac rehabilitation.
Class III (not indicated)	1. Severe comorbidity likely to limit life expectancy and/or candidacy for revascularization. 2. At any time to evaluate patients with acute myocardial infarction who have uncompensated congestive heart failure, cardiac arrhythmia, or noncardiac conditions that severely limit their ability to exercise. 3. Before discharge to evaluate patients who have already been selected for, or have undergone, cardiac catheterization. Although a stress test may be useful before or after catheterization to evaluate or identify ischemia in the distribution of a coronary lesion of borderline severity, stress imaging tests are recommended.

*Exceptions are noted under Classes IIb and III.

TABLE 10G–8 ACC/AHA Guidelines for Exercise Testing with Ventilatory Gas Analysis

	Indication
Class I (indicated)	1. Evaluation of exercise capacity and response to therapy in patients with heart failure who are being considered for heart transplantation. 2. Assistance in the differentiation of cardiac versus pulmonary limitations as a cause of exercise-induced dyspnea or impaired exercise capacity when the cause is uncertain.
Class IIa (good supportive evidence)	Evaluation of exercise capacity when indicated for medical reasons in patients in whom the estimates of exercise capacity from exercise test time or work rate are unreliable.
Class IIb (weak supportive evidence)	1. Evaluation of the patient's response to specific therapeutic interventions in which improvement of exercise tolerance is an important goal or endpoint. 2. Determination of the intensity for exercise training as part of comprehensive cardiac rehabilitation.
Class III (not indicated)	Routine use to evaluate exercise capacity.

TABLE 10G–9 ACC/AHA Guidelines for Exercise Testing in Asymptomatic Persons without Known Coronary Artery Disease (CAD)

	Indication
Class I (indicated)	None
Class IIa (good supportive evidence)	Evaluation of asymptomatic persons with diabetes mellitus who plan to start vigorous exercise.
Class IIb (weak supportive evidence)	1. Evaluation of persons with multiple risk factors as a guide to risk reduction therapy.* 2. Evaluation of asymptomatic men older than 45 years and women older than 55 years: • Who plan to start vigorous exercise (especially if sedentary) or • Who are involved in occupations in which impairment might impact public safety or • Who are at high risk for CAD due to other diseases (e.g., peripheral vascular disease and chronic renal failure)
Class III (not indicated)	Routine screening of asymptomatic men or women.

*Multiple risk factors are defined as hypercholesterolemia (>240 mg/dl), hypertension (systolic blood pressure > 140 mm Hg or diastolic blood pressure > 90 mm Hg), smoking, diabetes, and family history of heart attack or sudden cardiac death in a first-degree relative younger than 60 years. An alternative approach might be to select patients with a Framingham risk score consistent with at least a moderate risk of serious cardiac events within 5 years.

TABLE 10G–10 ACC/AHA Guidelines for Exercise Testing in Patients with Valvular Heart Disease

	Indication
Class I (indicated)	In chronic aortic regurgitation, assessment of functional capacity and symptomatic responses in patients with a history of equivocal symptoms.
Class IIa (good supportive evidence)	1. In chronic aortic regurgitation, evaluation of symptoms and functional capacity before participation in athletic activities. 2. In chronic aortic regurgitation, prognostic assessment before aortic valve replacement in asymptomatic or minimally symptomatic patients with left ventricular dysfunction.
Class IIb (weak supportive evidence)	Evaluation of exercise capacity in patients with valvular heart disease.
Class III (not indicated)	Diagnosis of coronary artery disease in patients with moderate to severe valvular disease or with the following baseline electrocardiographic abnormalities: • Preexcitation • Electronically paced ventricular rhythm • Greater than 1 mm ST depression • Complete left bundle branch block

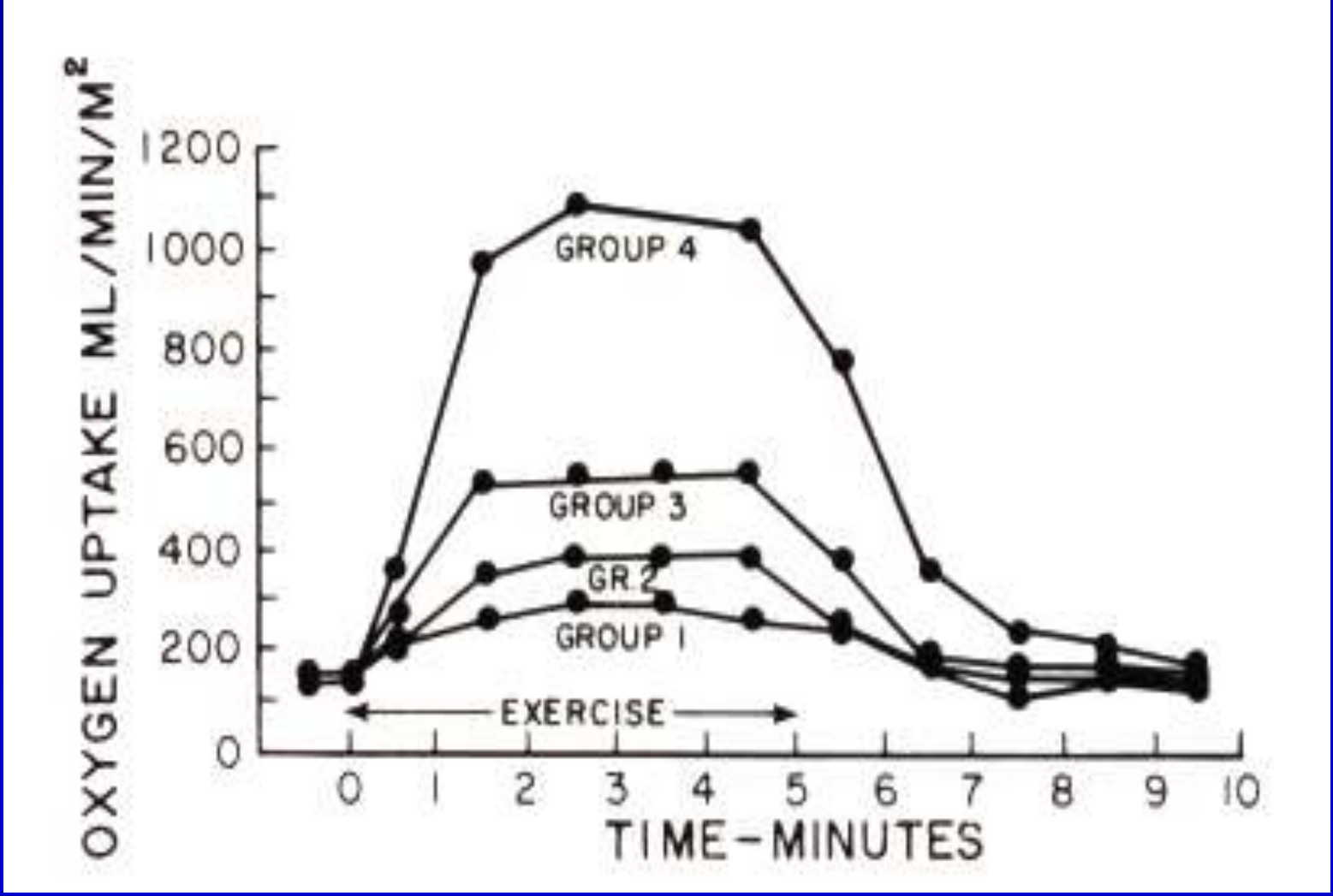
TABLE 10G–11 ACC/AHA Guidelines for Exercise Testing Before and After Revascularization

	Indication
Class I (indicated)	1. Demonstration of ischemia before revascularization. 2. Evaluation of patients with recurrent symptoms that suggest ischemia after revascularization.
Class IIa (good supportive evidence)	After discharge for activity counseling and/or exercise training as part of cardiac rehabilitation in patients who have undergone coronary revascularization.
Class IIb (weak supportive evidence)	1. Detection of restenosis in selected, high-risk asymptomatic patients within the first 12 months after percutaneous coronary intervention. 2. Periodic monitoring of selected, high-risk asymptomatic patients for restenosis, graft occlusion, incomplete coronary revascularization, or disease progression.
Class III (not indicated)	1. Localization of ischemia for determining the site of intervention. 2. Routine, periodic monitoring of asymptomatic patients after percutaneous coronary intervention or coronary artery bypass grafting without specific indications.

TABLE 10G–12 ACC/AHA Guidelines for Exercise Testing for Investigation of Heart Rhythm Disorders

	Indication
Class I (indicated)	1. Identification of appropriate settings in patients with rate-adaptive pacemakers. 2. Evaluation of congenital complete heart block in patients considering increased physical activity or participation in competitive sports.
Class IIa (good supportive evidence)	1. Evaluation of patients with known or suspected exercise-induced arrhythmias. 2. Evaluation of medical, surgical, or ablative therapy in patients with exercise-induced arrhythmias (including atrial fibrillation).
Class IIb (weak supportive evidence)	1. Investigation of isolated ventricular ectopic beats in middle-aged patients without other evidence of coronary artery disease. 2. Investigation of prolonged first-degree atrioventricular block or type I second-degree Wenckebach block, left bundle branch block, right bundle branch block, or isolated ectopic beats in young patients considering participation in competitive sports.
Class III (not indicated)	Routine investigation of isolated ectopic beats in young patients.

Oxygen Consumption during Exercise



From Grossman, 5th ed, 1996, p. 282; original 1955 Donald et al.

Upright vs Supine Exercise

- Resting cardiac output, LVEDV and SV are lower in upright posture
- With upright exercise, LVEDV and SV increase up to a point of about 50% of peak Oxygen consumption, then plateau

Effects of Age and Gender on Exercise Response

- In youth, LVEDP decreases or is constant during supine exercise
- In elderly, LVEDP generally rises
  - 10 normal men age 46, supine LVEDP rose from 8 to 16, and sitting LVEDP rose from 4 to 11
- In women, increase in SV sitting is from increase in LVEDV without increase in EF, but in men the EF increases progressively

Exercise in Diastolic Dysfunction

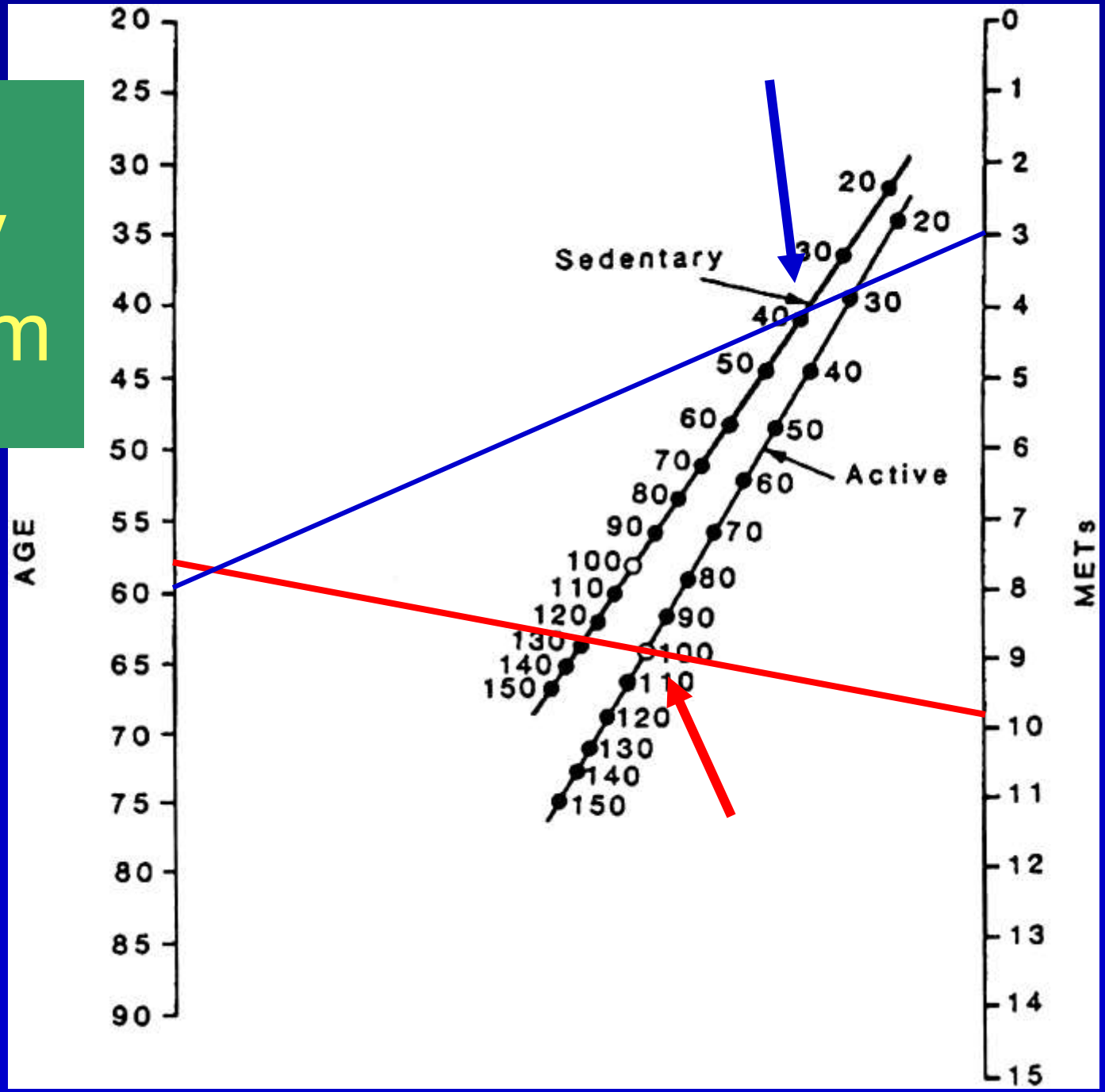
- LV relaxation is slow (long tau)
- Depressed relaxation worsens in tachycardia
- With small resting LV end-systolic volume, exercise enhancement is attenuated
- Ischemia during tachycardia is more likely in hypertrophy - impaired distensibility

Exercise Testing Usefulness

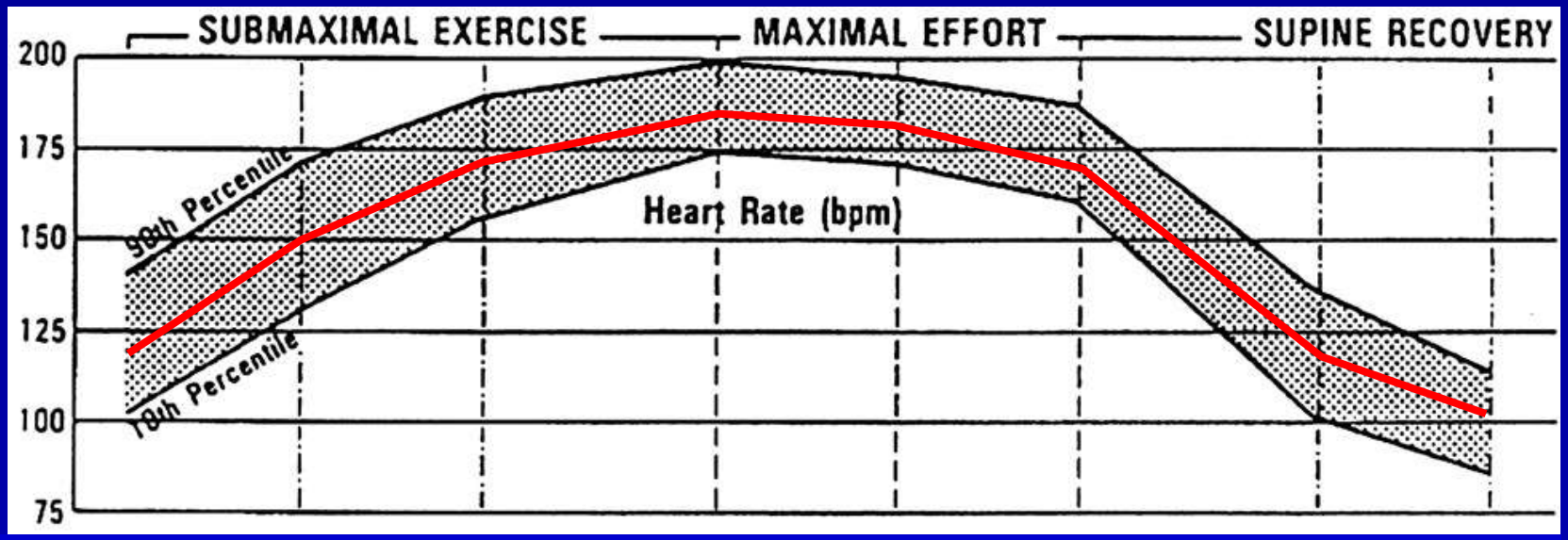
- Diagnosis
- Severity of disease or risk assessment or prognosis
  - known or suspected chronic coronary disease
- Risk assessment after MI
- Stress testing with ventilatory gas analysis
- Specific Clinical Populations
- Pediatric Populations

ETT Guidelines, 2002

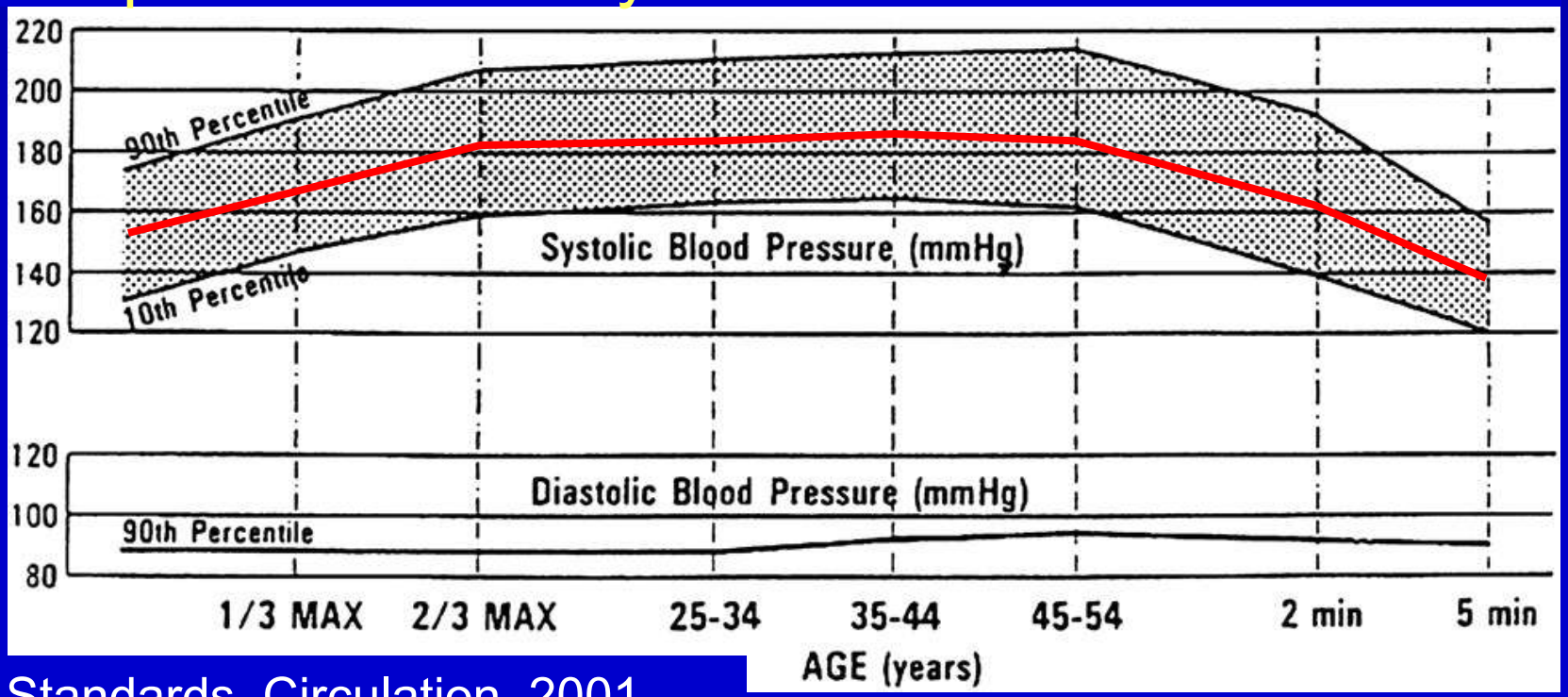
Aerobic Capacity Nomogram (men)



Exercise Standards. Circulation. 2001.

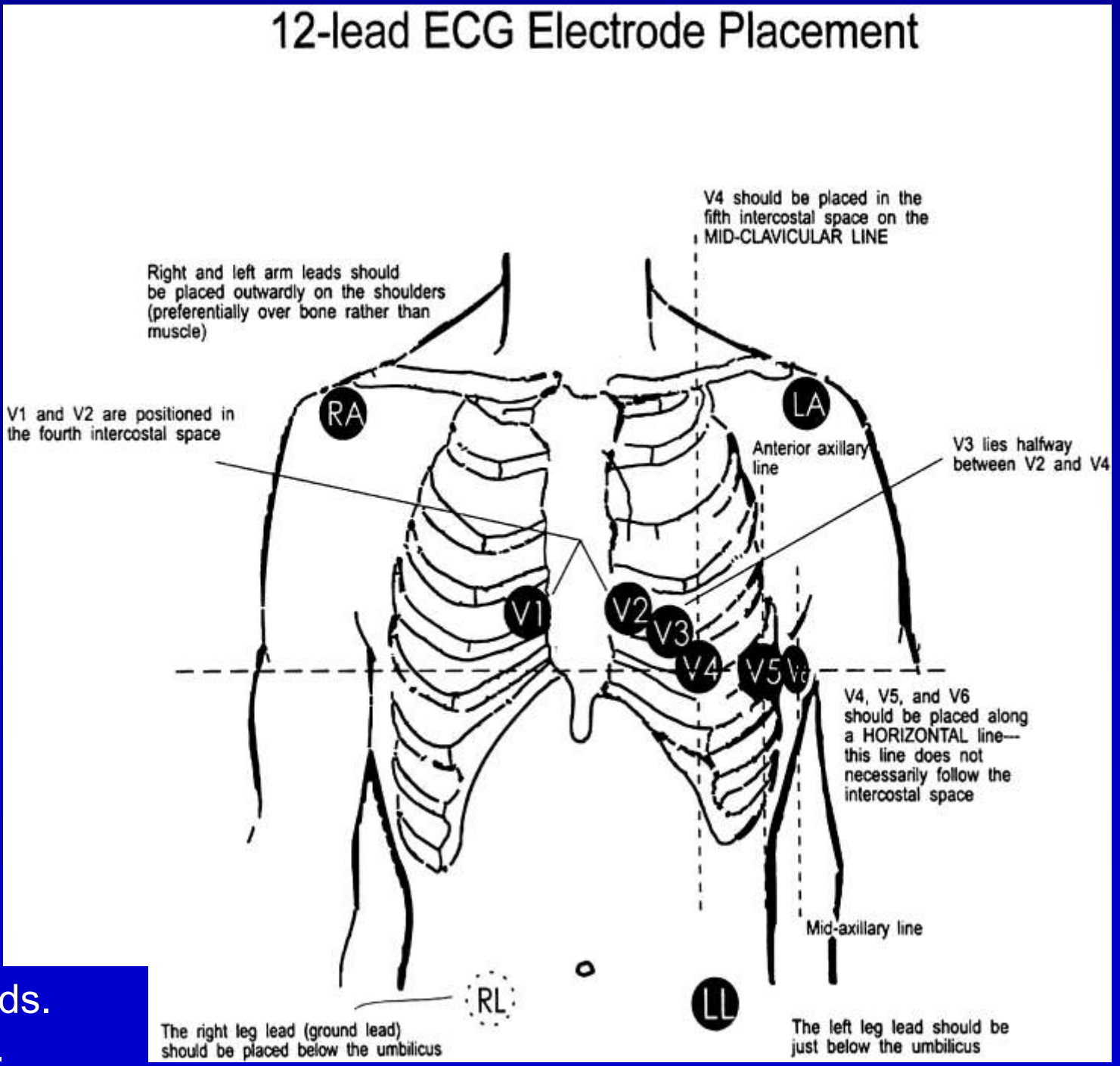


The Response of Healthy Men to Treadmill Exercise



Exercise Standards. Circulation. 2001.

12-lead ECG Electrode Placement

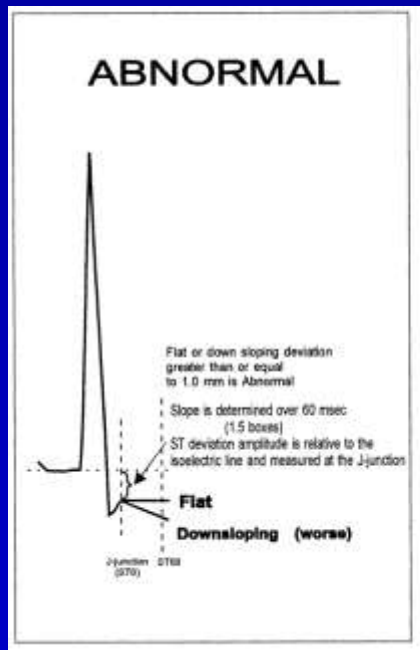


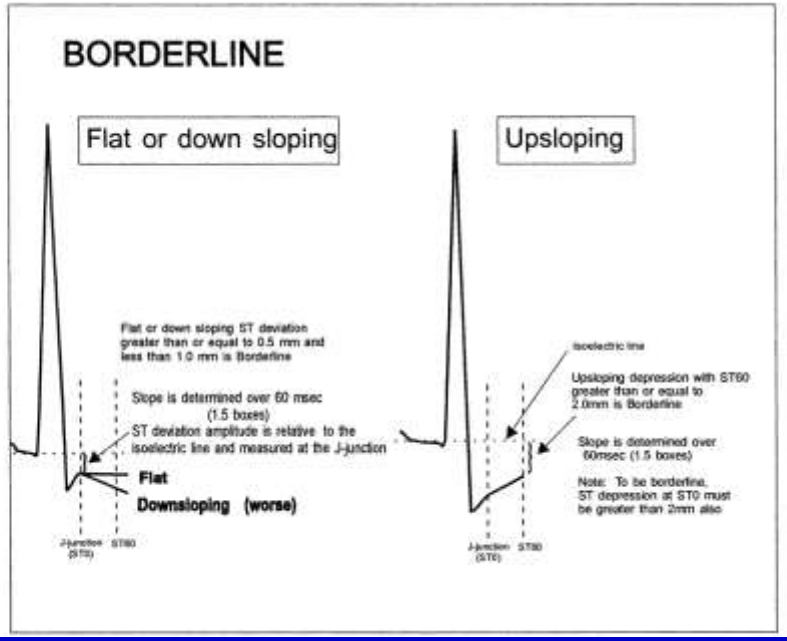
Exercise Standards. Circulation. 2001.

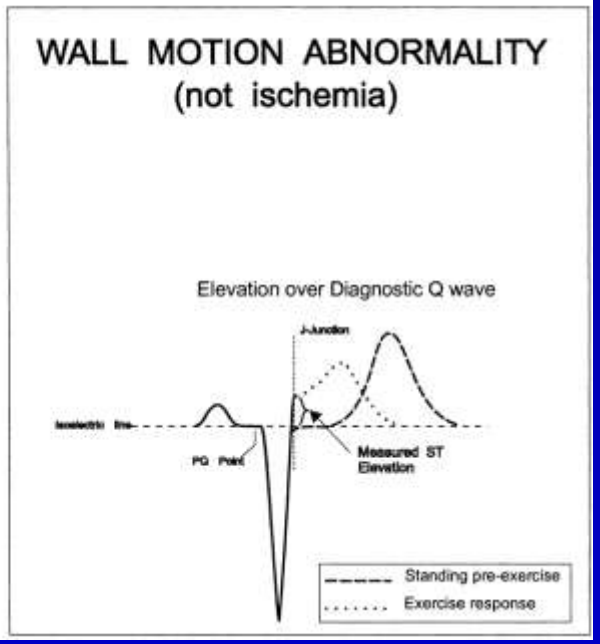
FUNCTIONAL CLASS	CLINICAL STATUS			O_2 COST ml/kg/min	METS	BICYCLE ERGOMETER	TREADMILL PROTOCOLS				METS
						1 WATT = 6.1 Kpm/min FOR 70 KG BODY WEIGHT Kpm/min	BRUCE MODIFIED 3 min Stages MPH %GR		BRUCE 3 min Stages MPH %GR		NAUGHTON 2 min Stages MPH %GR	
							6.0	22	6.0	22		
							5.5	20	5.5	20		
NORMAL AND I	HEALTHY, DEPENDENT ON AGE, ACTIVITY											
							5.0	18	5.0	18		
				56.0	16							16
				52.5	15							15
				49.0	14							14
				45.5	13	1500	4.2	16	4.2	16		13
				42.0	12	1350						12
				38.5	11	1200	3.4	14	3.4	14		11
				35.0	10	1050						10
				31.5	9						2 17.5	9
				28.0	8	900					2 14.0	8
				24.5	7	750	2.5	12	2.5	12		7
II				21.0	6	600					2 10.5	6
				17.5	5	450	1.7	10	1.7	10	2 7.0	5
III				14.0	4	300					2 3.5	4
				10.5	3		1.7	5			2 0	3
				7.0	2	150						2
							1.7	0			1 0	
IV				3.5	1							1

Exercise Standards. Circulation. 2001.

ST Segment Analysis

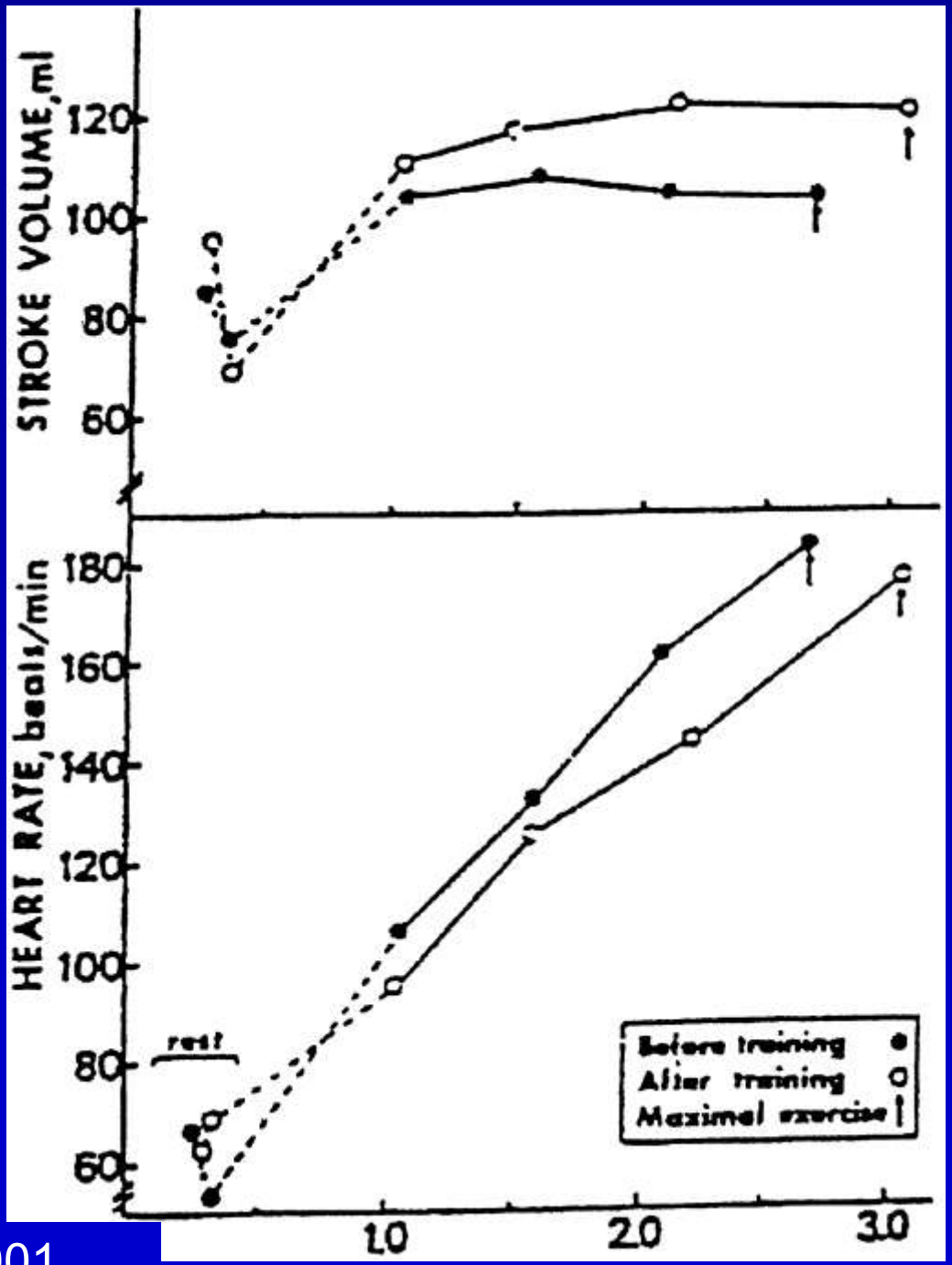




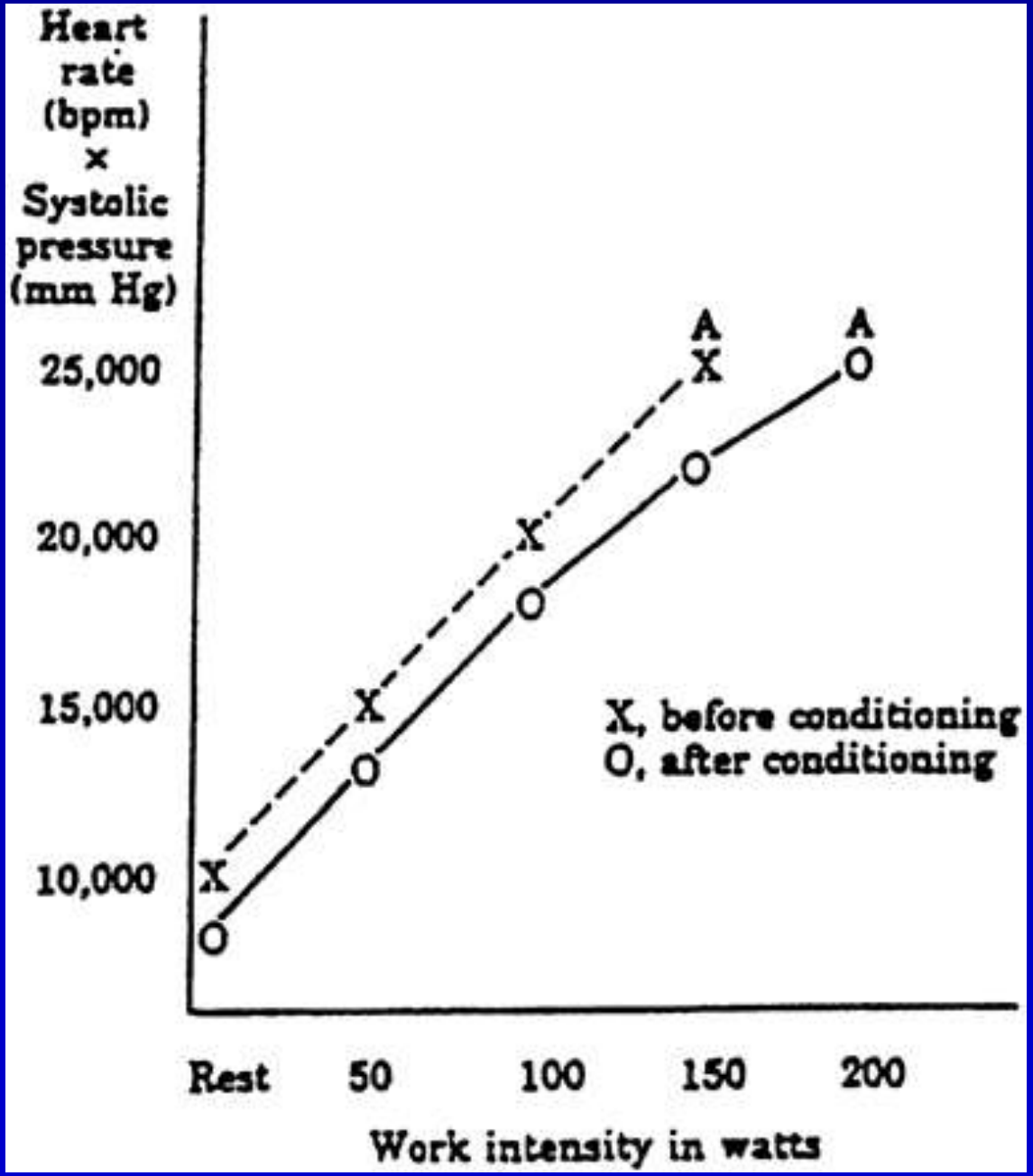


Exercise Standards. Circulation. 2001.

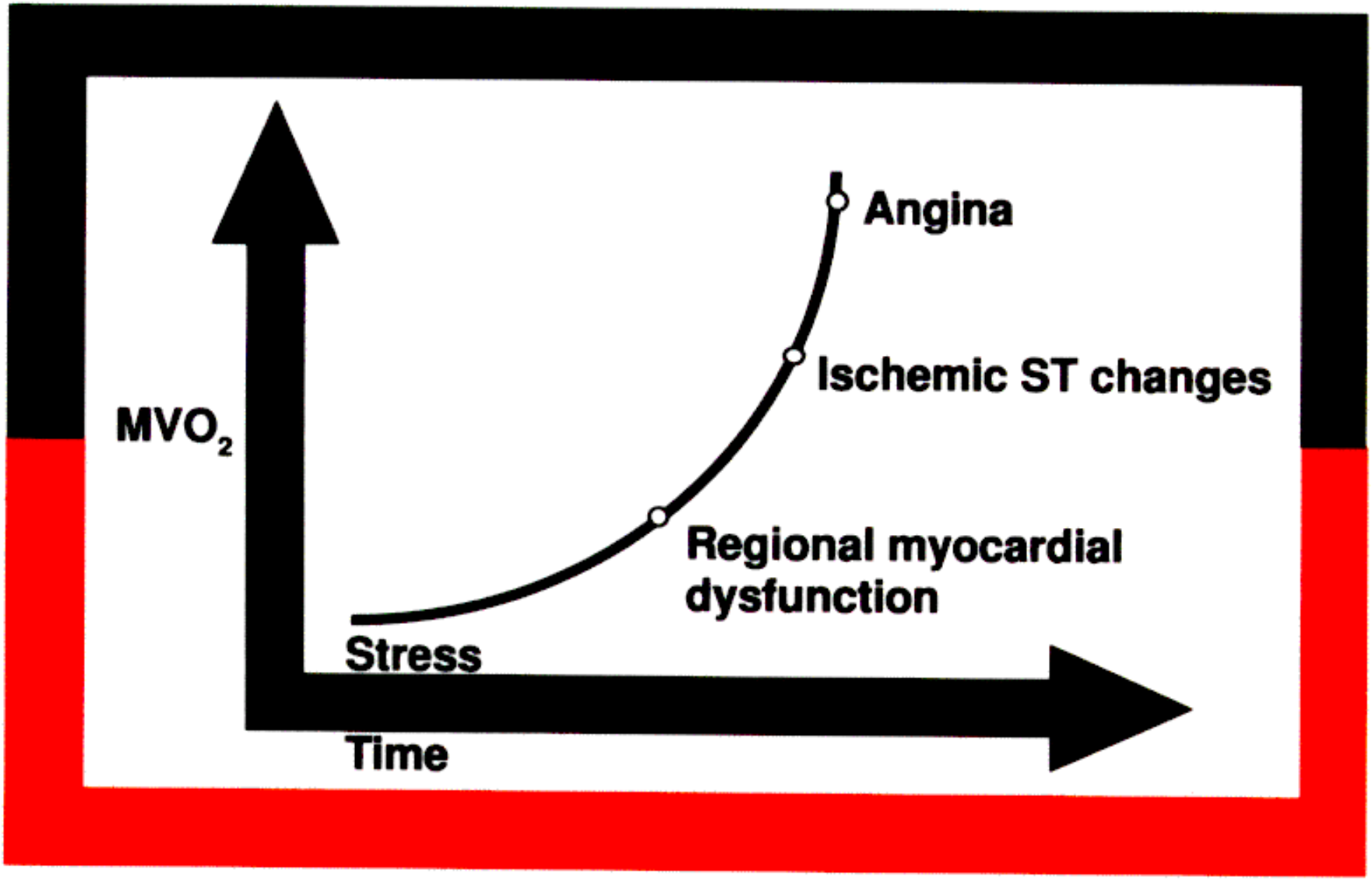
Training Effects



Exercise Standards. Circulation. 2001.



Exercise Standards. Circulation. 2001.



Ischemic Cascade

Exercise Testing Procedure

- MI or death in 1:2500 tests (safer than DSE)
- Supervised by appropriately trained physician, or others if physician immediately available for emergencies
- Each Stage - BP, HR, EKG, continuous rhythm
- Guidelines 2001 for Exercise Laboratories

ETT Guidelines, 2002

Exercise Equipment and Protocols

- Treadmill or cycle ergometer
- Customize protocol to allow 6 to 12 minutes of exercise
- Report in METS (2, 3-4, 5, 7, 10, 13)
  - Bruce: 3 min is **5** METs, 6 min is **7** METs, 9 min is **10** METs, 12 min is **13** METs.
  - Modified Bruce: 3 min is 2 METs, 6 min is 3-4 METs

What is a MET?

ETT Guidelines, 2002

Functional class	Clinical status	O_2 cost ml/kg/min	METS*	Bicycle ergometer	Treadmill protocols					METS
					Bruce	Balke-Ware	Ellestad	McHenry	Naughton	
				1 watt = 6 Kpds	3-min stages	%GR at 3.3 mph 1-min stages	3/2/3 min stages		2-min stages 3.0 mph %GR	
				For 70 kg body weight Kpds	mph %GR		mph %GR			
					5.5 2.0					
		56.0	16		5.0 18		6 15		32.5	16
		52.5	15						30.0	15
		49.0	14	1500			5 15	mph %GR	27.5	14
		45.5	13		4.2 16			3.3 21	25.0	13
		42.0	12	1350				3.3 18	22.5	12
		38.5	11	1200			5 10	3.3 15	20.0	11
		35.0	10	1050					17.5	10
		31.5	9		3.4 14				15.0	9
		28.0	8	900			4 10			
		24.5	7	750				3.3 12	12.5	8
		21.0	6		2.5 12		3 10		10.0	7
		17.5	5	600				3.3 9	7.5	6
		14.0	4	450	1.7 10		1.7 10	3.3 6	5.0	5
		10.5	3	300					2.5	4
		7.0	2		1.7 5			2.0 3	0.0	3
		3.5	1	150						2
					1.7 0					1

Normal and I

II

III

IV

Healthy, dependent on age, activity

Sedentary healthy

Limited

Symptomatic

26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

mph = miles per hour; %GR = percent grade; Kpds = kiloponds

Fletcher GF et al, CPC, 1998

*1 MET = body O2 consumption at rest, sitting

Exercise Testing: Absolute Contraindications

- MI within 2 days
- High risk unstable angina
- Uncontrolled symptomatic or hemodynamically significant arrhythmias
- Symptomatic severe aortic stenosis
- Uncontrolled symptomatic heart failure
- Acute pulmonary embolus/infarction
- Acute myocarditis/pericarditis/dissection

ETT Guidelines, 2002

Exercise Testing: Relative Contraindications

- Left main coronary stenosis
- Moderate stenotic valvular heart disease
- Electrolyte abnormalities
- Severe hypertension (SBP>200, DBP>110)
- High degree AV block, tachy or brady
- HCM or other LVOT or RVOT obstruction
- Inability to adequately exercise

ETT Guidelines, 2002

Exercise Testing: Absolute Endpoints

- SBP drop >10mmHg from *baseline* with other evidence of ischemia
- Moderate or severe angina
- Increasing CNS symptoms (ataxia, dizziness, syncope) or desire to stop
- Signs of poor perfusion (cyanosis or pallor)
- Unable to measure BP or see ECG
- ST elevation >0.1mV (not V1 or aVR or MI lead)
- Sustained VT

ETT Guidelines, 2002

Exercise Testing: Relative Endpoints

- SBP drop >10mmHg from baseline - no evidence of ischemia
- ST depression >2mm, or marked axis shift
- Multifocal PVC's, triplets, SVT, heart block, bradyarrhythmias, can't R/O VT
- Fatigue, SOB, wheeze, claudication
- SBP>250, DBP >115
- Increasing chest pain

ETT Guidelines, 2002

Exercise Test Interpretation

- ECG Response - most important - 0.1mV horizontal or downsloping ST depression or elevation for at least 60-80 msec

- Exercise capacity
- Clinical response
- Hemodynamic response
- Chest discomfort, especially if it is limiting

ETT Guidelines, 2002

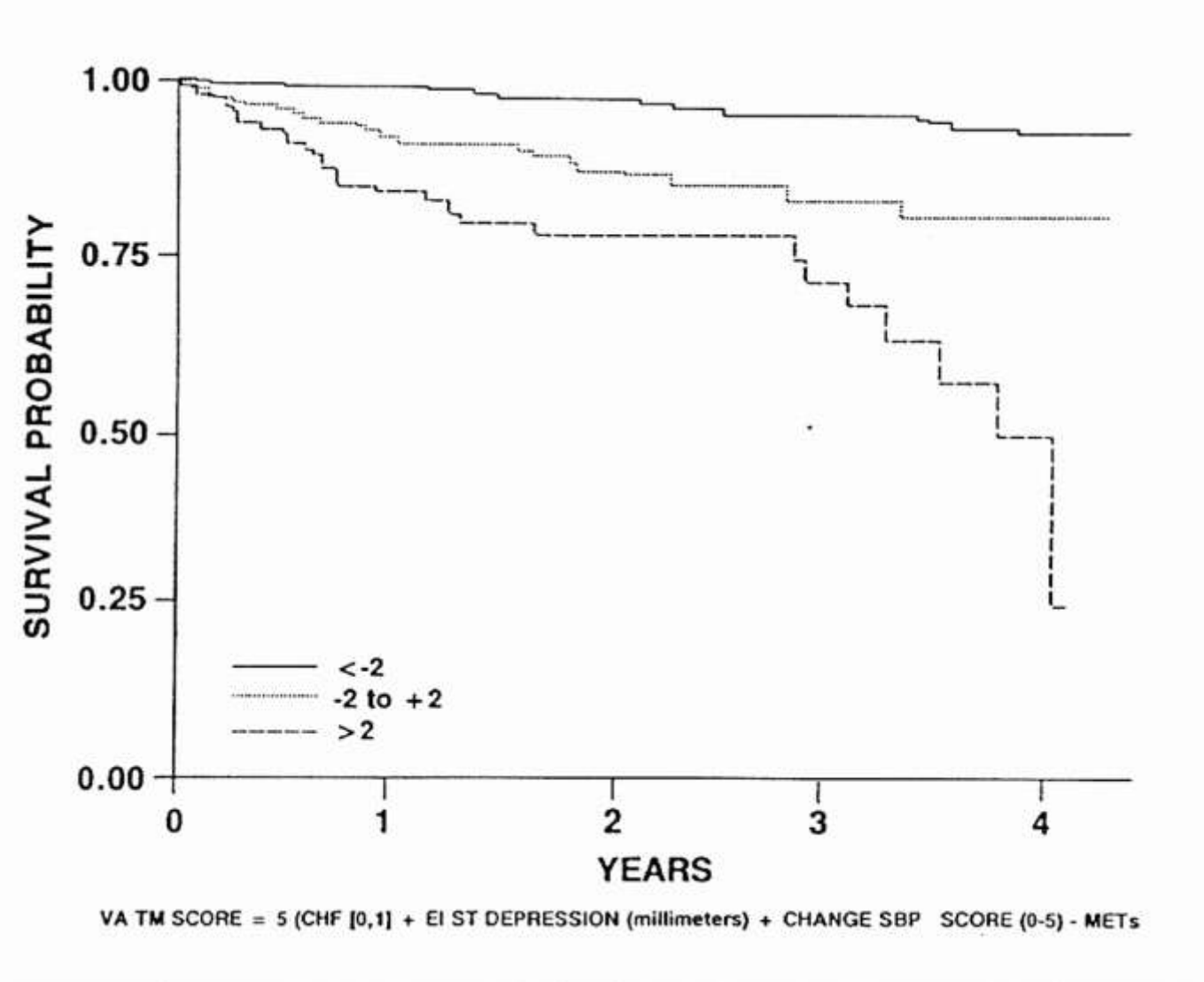
Exercise Test Interpretation

- Blood Pressure Response – Long Beach VA Hospital study: risk score based on formula:
- 5x(CHF/Digoxin 1=y, 0=n) + ST dep (mm) + ΔBP – Mets
  - ΔBP score: >40=0, 30-40=1, 20-30=2, 10-20=3, 0-10=4, <0=5

• Score <-2	Low risk 77%	<2% ann mort
• Score -2 to 2	Mod risk 18%	7% ann mort
• Score >2	High risk 6%	15% ann mort

Morrow K et al. Ann Intern Med. 1993;118:689.

Exercise Test Interpretation



Morrow K et al. Ann Intern Med. 1993;118:689.

Clinical Features of the Total Study Population and Number and Percentage with a Given End Point

Variable	Total Sample (n = 2546)	No Cardiovascular Event (n = 2285)	Cardiovascular Deaths (n = 119)	Nonfatal Myocardial Infarction (n = 44)	P Value*
Mean age (± 1 SD), *y*	59 ± 10	58 ± 10	63 ± 7	58 ± 8	< 0.001
Chest pain presentation, *n(%)*					
Typical angina	547 (21)	472 (21)	29 (24)	12 (27)	0.03
History of congestive heart failure or digoxin use	277 (11)	212 (9)	37 (31)	5 (11)	< 0.001
History of myocardial infarction	577 (23)	470 (21)	48 (40)	16 (36)	< 0.001
Submaximal treadmill because of recent myocardial infarction, *n(%)*	176 (7)	137 (6)	16 (13)	7 (16)	< 0.001
Beta-blocker use, *n(%)*	551 (22)	480 (21)	27 (23)	15 (34)	< 0.001
Digitalis use, *n(%)*	193 (8)	152 (7)	26 (22)	2 (4)	< 0.001
Q waves on electrocardiogram, *n(%)*	530 (21)	438 (19)	46 (39)	17 (39)	< 0.001
Anterior Q waves, *n(%)*	181 (7)	144 (6)	20 (17)	7 (16)	< 0.001
More than one Q-wave area, *n(%)*	66 (3)	49 (2)	8 (7)	4 (9)	0.002
Resting ST depression, *n(%)*	142 (6)	110 (5)	16 (13)	4 (9)	< 0.001
Left ventricular hypertrophy, *n(%)*	141 (6)	111 (5)	14 (12)	4 (9)	0.0004

* Between no cardiovascular event and cardiovascular death. Determined by *t*-test or chi-square test.

Morrow, K. et. al. Ann Intern Med 1993;118:689-695

Annals of Internal Medicine

Hemodynamic and Exercise Electrocardiographic Features of the Total Study Population*

Variable	Total Sample (n = 2546)	No Cardiovascular Event (n = 2285)	Cardiovascular Deaths (n = 119)	Nonfatal Myocardial Infarction (n = 44)	P Value†
Hemodynamic responses					
Maximum METs	8.4 ± 3.7	8.7 ± 3.7	5.6 ± 2.9	6.5 ± 2.9	< 0.001
Age adjusted normal, %	93 ± 38	95 ± 37	67 ± 33	71 ± 29	< 0.001
Angina pectoris, *n(%)*	109 (4)	91 (4)	2 (2)	2 (5)	< 0.001
Maximal heart rate, *bpm*	137 ± 25	138 ± 25	125 ± 25	126 ± 25	< 0.001
Change in heart rate, *bpm*	58 ± 24	60 ± 24	44 ± 22	49 ± 19	< 0.001
Maximal systolic blood pressure, *mm Hg*	175 ± 29	176 ± 29	157 ± 32	156 ± 26	< 0.001
Maximal change in systolic blood pressure, *mm Hg*	45 ± 26	47 ± 25	27 ± 25	27 ± 25	< 0.001
Systolic blood pressure drop below rest, *n(%)*	80 (3)	59 (3)	11 (9)	3 (7)	<0 .001
Maximal DP, $\times 10^{-3}$	24.2 ± 6.9	24.7 ± 6.8	19.7 ± 6.4	20.0 ± 6.2	< 0.001
Less than 5000 dpdif, *n(%)*	171 (7)	122 (5)	27 (23)	10 (23)	< 0.001
Claudication, *n(%)*	92 (4)	75 (3)	9 (8)	2 (5)	< 0.01
Exercise electrocardiographic data, *n(%)*					
> 1.0 mm ST depression	550 (22)	440 (19)	44 (37)	18 (41)	< 0.001
> 3.0 mm ST depression	85 (3)	54 (2)	10 (8)	4 (9)	<0 .0001
ST segment elevation	77 (3)	60 (3)	12 (10)	2 (5)	< 0.001
Frequent premature ventricular contractions	123 (5)	107 (5)	9 (8)	1 (2)	0.2

* MET = multiple of the resting energy expenditure; 1 = 3.5 mL O_2/kg body weight × min. Where appropriate, values are given as mean ± 1 SD. DP = double product of systolic blood pressure × heart rate; dpdif = change in double product from before to maximal exercise.

† Between no cardiovascular event and cardiovascular death.

Annals of Internal Medicine

Morrow, K. et. al. Ann Intern Med 1993;118:689-695

Score Test Statistics for the Variables Considered in the Cox Proportional Hazard Model*

Variable	Cardiovascular Death		Infarct-free Survival	
	STS	*P* Value	STS	*P* Value
Clinical				
Age	17	< 0.001	9.6	0.002
Age > 70 years	6.6	0.01	5.5	0.02
Digoxin use	48	< 0.001	27	< 0.001
Beta-blocker use	0.2	0.6	0.06	0.8
Predischarge after myocardial infarction	10	0.002	9.5	0.002
Previous myocardial infarction	29	< 0.001	26	< 0.001
Typical angina pectoris	1.0	0.3	2	0.15
History of congestive heart failure	28	< 0.001	30	< 0.001
Digoxin use or history of congestive heart failure	62	< 0.001	41	< 0.001
More than one Q-wave area	10	0.001	16	< 0.001
Anterior Q wave	19	< 0.001	25	< 0.001
Left ventricular hypertrophy	13	< 0.001	13	< 0.001
Resting ST depression	12	< 0.001	12	< 0.001
History of claudication	2	0.2	0.6	0.4
Hemodynamic				
Maximal heart rate	23	< 0.001	30	< 0.001
Maximal heart rate > 140 bpm	21	< 0.001	19	< 0.001
Maximal heart rate < 100 bpm	17	< 0.001	28	< 0.001
Maximal systolic blood pressure	51	< 0.001	62	< 0.001
Systolic blood pressure drop below standing rest	17	< 0.001	14	< 0.001
Systolic blood pressure difference	62	< 0.001	74	< 0.001
Systolic blood pressure change score	71	< 0.001	89	< 0.001
METs achieved in exercise test	67	< 0.001	65	< 0.001
Less than five multiples of basal oxygen cost	70	< 0.001	65	< 0.001
Maximal double product	50	< 0.001	61	< 0.001
Double product difference < 9000	54	< 0.001	63	< 0.001
Double product difference < 5000	64	< 0.001	80	< 0.001
Electrocardiographic and ischemic				
ST elevation over Q waves	23	< 0.001	14	< 0.001
Maximal ST depression	57	< 0.001	51	< 0.001
ST depression of 1 mm	19	< 0.001	31	< 0.001
ST depression of 2 mm	12	< 0.001	23	< 0.001
ST depression of 3 mm	17	< 0.001	32	< 0.001
Frequent premature ventricular contractions	3	0.07	2	0.2
Angina pectoris during exercise test	0.4	0.5	0.3	0.6
Exercise test stopped due to claudication	9.4	0.002	7	0.007

* METs = multiples of resting energy expenditure; STS = score test statistic, which is asymptotically equivalent to the likelihood ratio and the Wald tests. It is the quadratic form based on the first step of the Newton-Raphson fitting procedure performed by EGRET. The STS is compared with a chi-square distribution having the same degrees of freedom. It represents the relative importance of the variable in the Cox model.

Morrow, K. et. al. Ann Intern Med 1993;118:689-695

Annals of Internal Medicine

Performance of the Clinical Exercise Test Score Derived from the Cox Proportional Hazards Model for Predicting Cardiac Death*

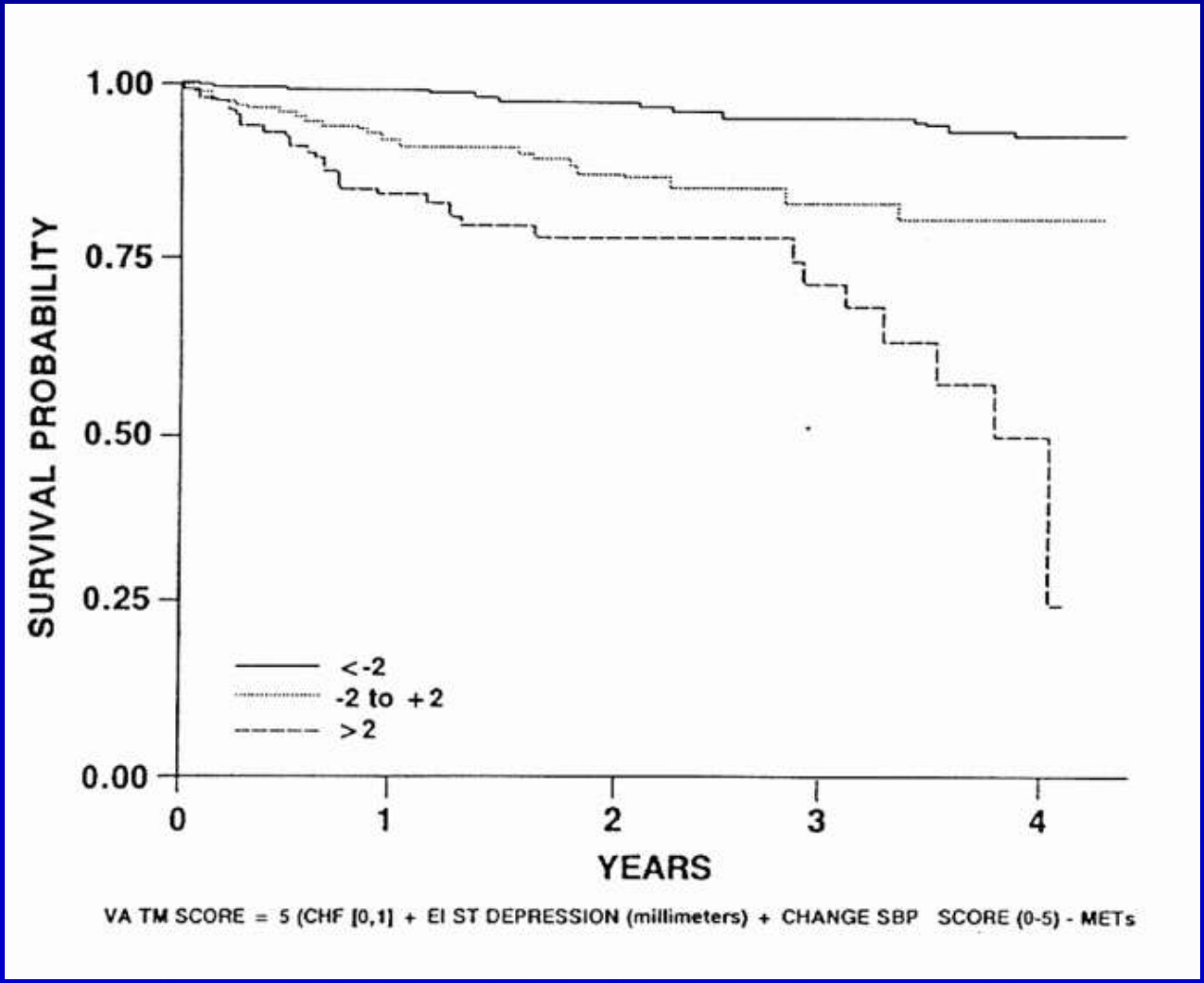
Clinical Exercise Score	Hazard Ratio (95% CI)	*P* Value	STS†
A	1		
B	4 (3 to 7)	< 0.001	33
C	11 (7 to 17)	< 0.001	106

* A = treadmill score of < −2 (low risk); B = treadmill score of −2 to 2 inclusively (moderate risk); C = treadmill score of > 2 (high risk).
† STS = score test statistic, indicating the relative weight of the variable in the Cox model.

Morrow, K. et. al. Ann Intern Med 1993;118:689-695

Annals of Internal Medicine

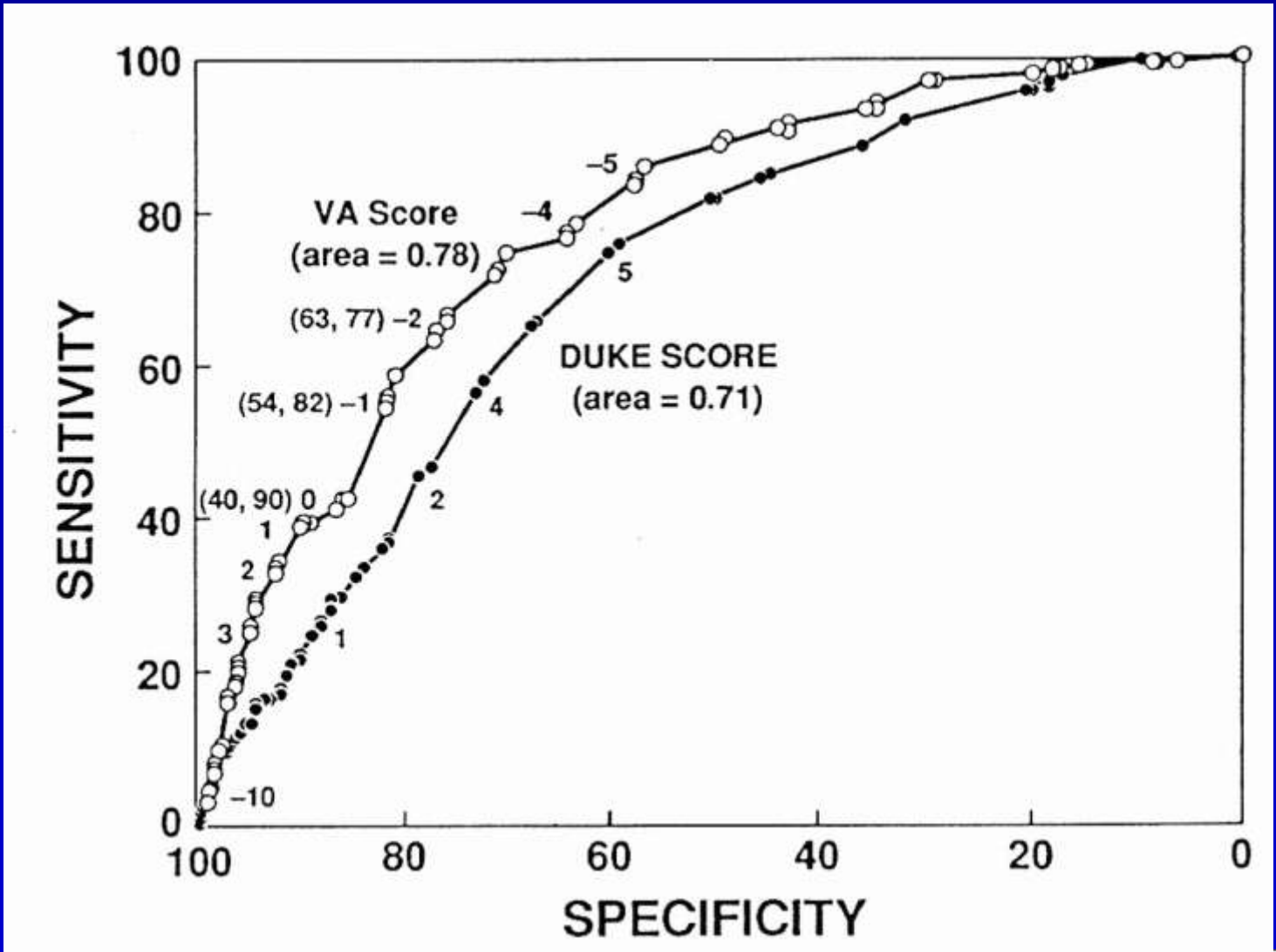
Kaplan-Meier survival curves using the clinical-exercise test score to predict cardiovascular death



Morrow, K. et. al. Ann Intern Med 1993;118:689-695

Annals of Internal Medicine

Receiver operating characteristic curves using the Duke treadmill score and the Veterans Affairs clinical-exercise test score to predict cardiovascular deaths (the numbers along the curves are respective cut-points of the scores)



Morrow, K. et. al. Ann Intern Med 1993;118:689-695

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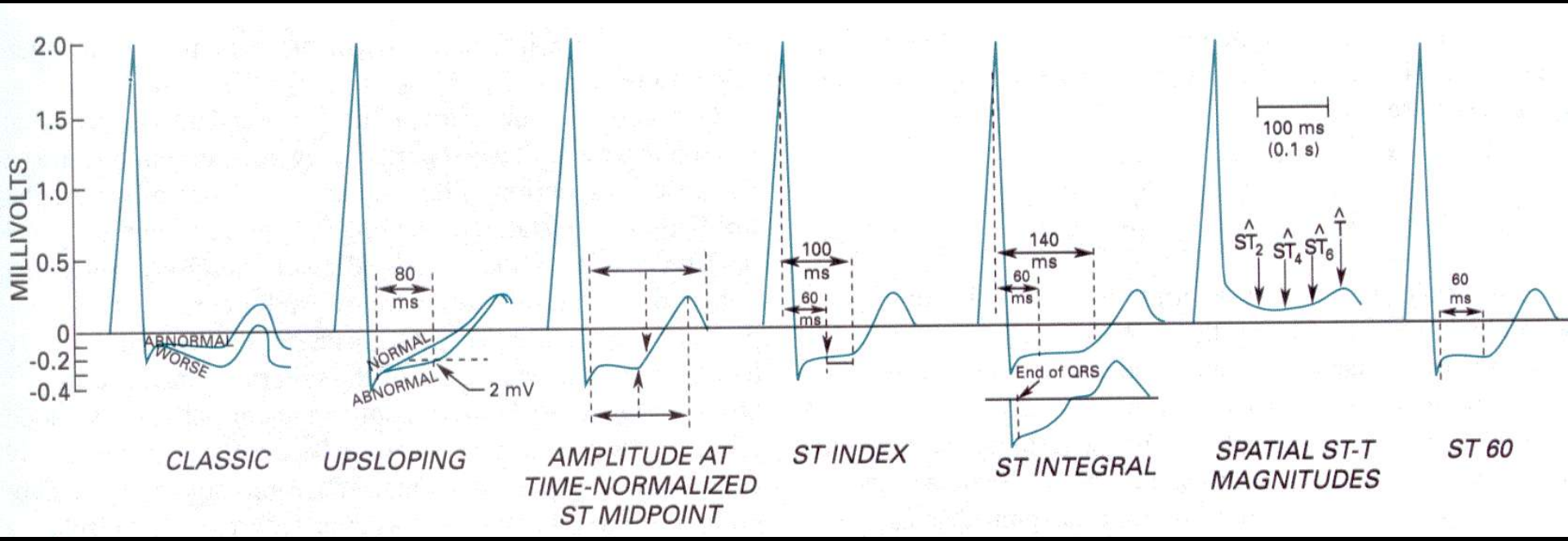
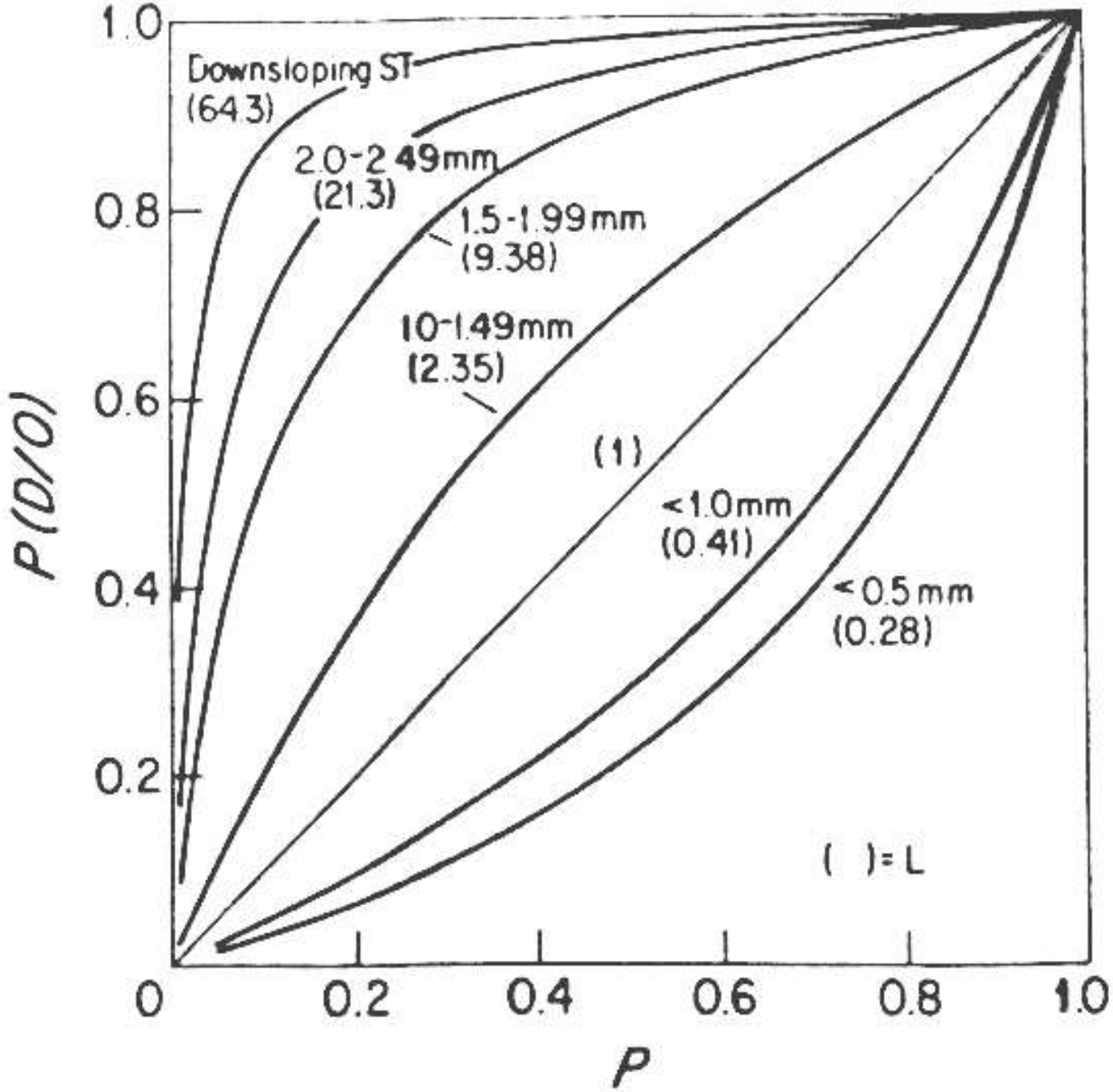
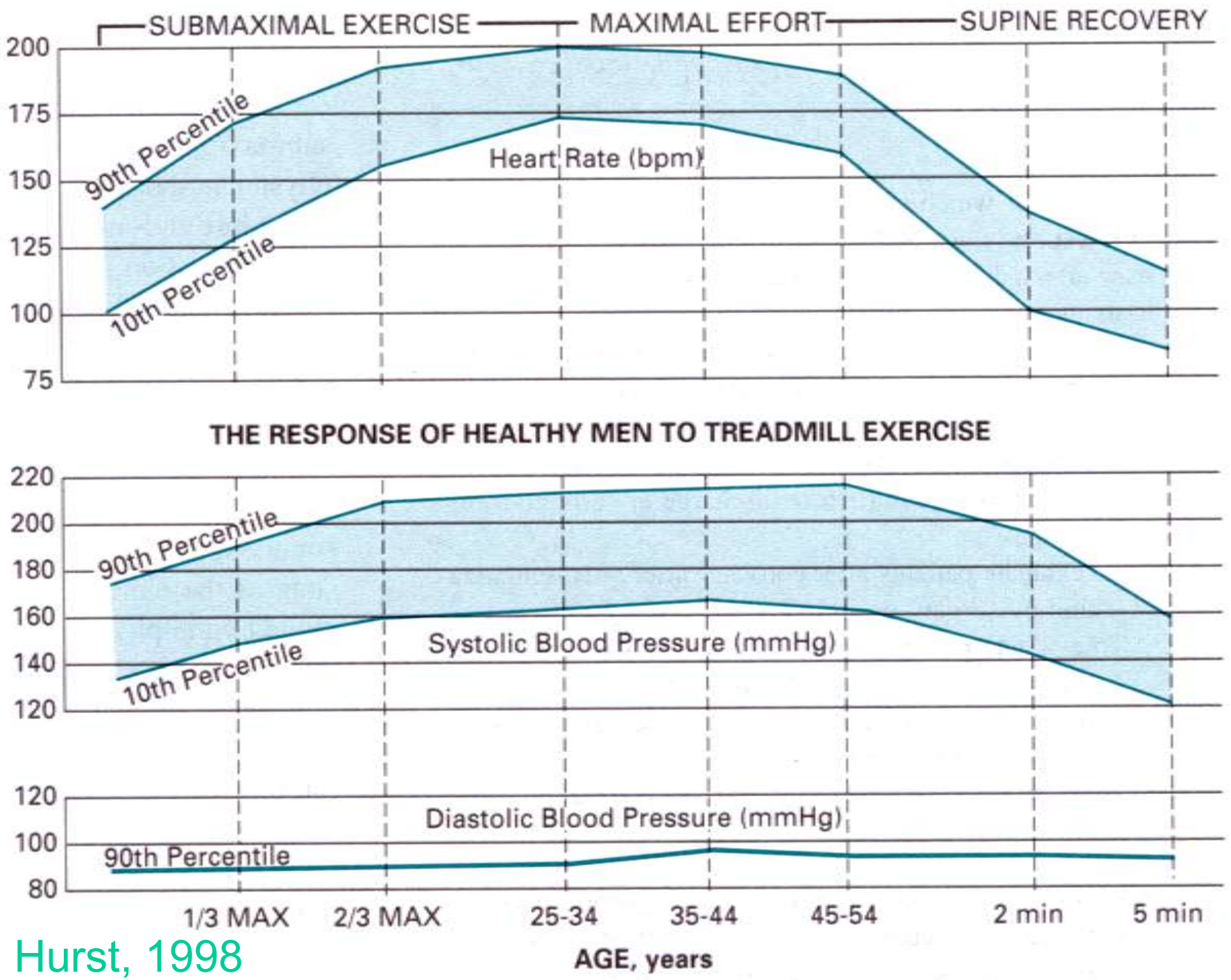

MILLIVOLTS
2.0
1.5
1.0
0.5
0
-0.2
-0.4
ABNORMAL
WORSE
80
ms
NORMAL
ABNORMAL
2 mV
100
ms
60
ms
140
ms
60
ms
End of QRS
100 ms
(0.1 s)
ST2 ST4 ST6 T
60
ms
CLASSIC
UPSLOPING
AMPLITUDE AT
TIME-NORMALIZED
ST MIDPOINT
ST INDEX
ST INTEGRAL
SPATIAL ST-T
MAGNITUDES
ST 60

Hurst, 1998


1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0
P(D/O)
P
Downsloping ST
(64.3)
2.0-2.49mm
(21.3)
1.5-1.99mm
(9.38)
1.0-1.49mm
(2.35)
(1)
<1.0mm
(0.41)
<0.5mm
(0.28)
( )= L

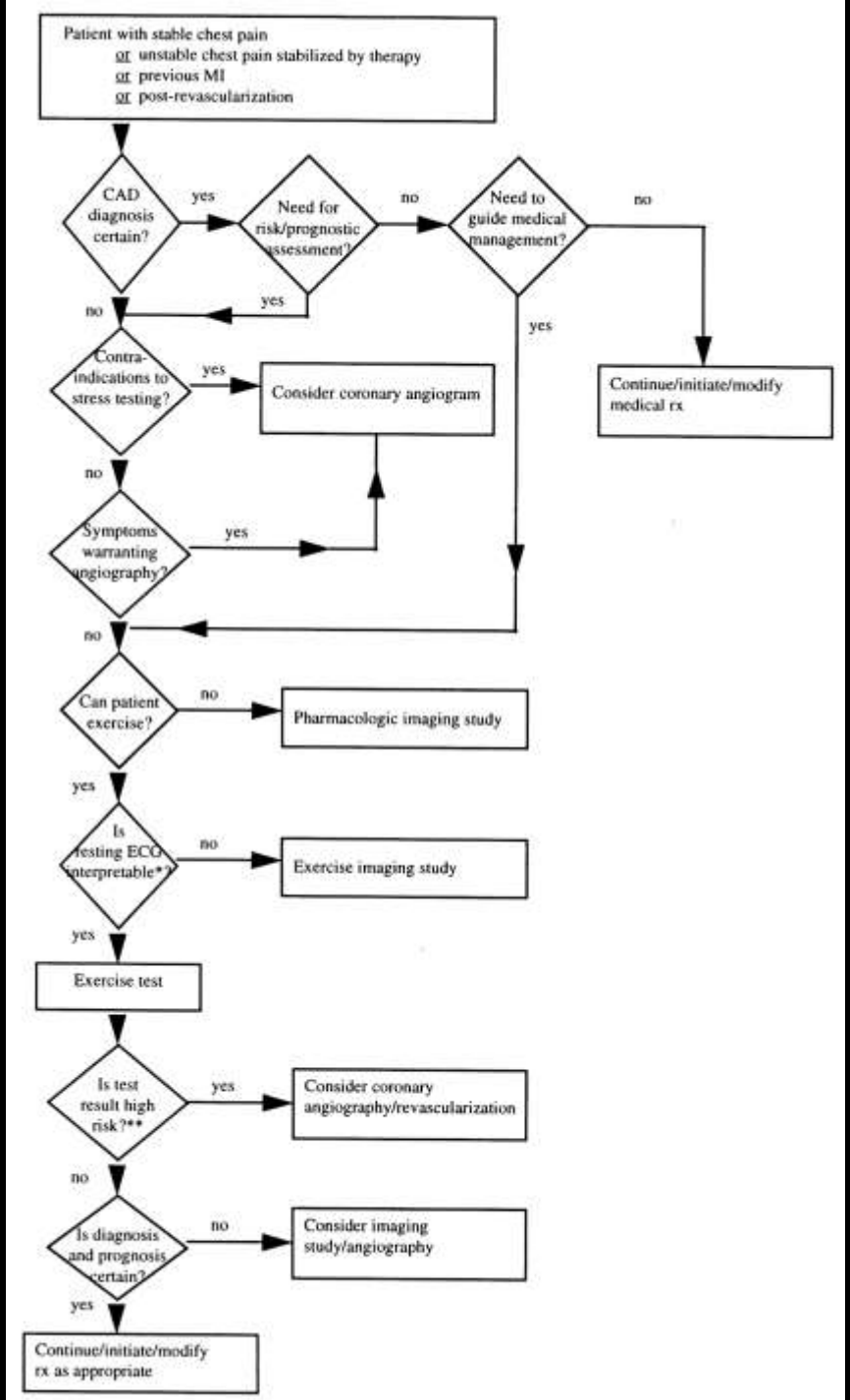

SUBMAXIMAL EXERCISE
MAXIMAL EFFORT
SUPINE RECOVERY
200
175
150
125
100
75
90th Percentile
Heart Rate (bpm)
10th Percentile
THE RESPONSE OF HEALTHY MEN TO TREADMILL EXERCISE
220
200
180
160
140
120
90th Percentile
10th Percentile
Systolic Blood Pressure (mmHg)
120
100
80
Diastolic Blood Pressure (mmHg)
90th Percentile
1/3 MAX
2/3 MAX
25-34
35-44
45-54
2 min
5 min
AGE, years

Hurst, 1998

Exercise Testing Indications

- Diagnosis of obstructive coronary artery disease
- Risk assessment and prognosis in patients with symptoms or a prior history of CAD
- After myocardial infarction
- Using ventilatory gas analysis
- Special groups (women, asymptomatic, elderly, valvular disease, hypertension, arrhythmias, pre- and post-revascularization)
- Children and adolescents

ETT Guidelines, 2002



ETT Guidelines, 1997 and 2002

Exercise Testing for Diagnosis of Coronary Artery Disease - 1

- Class I - adults with intermediate pretest probability based on gender, age, and sx
  - Includes RBBB and less than 1 mm ST depression
- Class IIa - vasospastic angina
- Class IIb - high or low pretest probability, less than 1mm baseline ST depression and digoxin, ECG-LVH with less than 1mm ST depression

ETT Guidelines, 2002

Exercise Testing for Diagnosis of Coronary Artery Disease - 2

- Class III: (Uninterpretable ECG)
  - WPW,
  - Paced rhythm,
  - greater than 1mm ST depression,
  - LBBB
- Class III:
  - prior diagnosis by MI or angiography

ETT Guidelines, 2002

Exercise Testing for Diagnosis - Definitions

- Definite or typical angina - all 3:
  - substernal chest pain or discomfort
  - provoked by exertion or emotional stress
  - relieved by NTG and rest
- Probable or atypical angina is 2 out of 3
- Intermediate probability is defined as 10-90% … see next slide

ETT Guidelines, 2002

Exercise Testing for Diagnosis: Intermediate Probability

	MEN	WOMEN
Typical Angina	Under 40	Under 60
Atypical Angina	All ages	Over 50
Nonanginal pain	Over 40	Over 60
Asymptomatic	None	None

ETT Guidelines, 2002

Exercise Testing for Diagnosis

- Abnormal is 1 mm horizontal ST shift
- “Upsloping ST depression should be considered borderline or negative”
- Sensitivity - 50-70% for 1 mm (50%)
- Specificity - 70-90% for 1 mm (90%)
- Population-dependent

ETT Guidelines, 2002

Exercise Testing for Diagnosis Drug Effects

- Digoxin produces ST depression in 25-40% of normals
- Nitrates and beta-blocker can decrease sensitivity, but may be continued
- Flecainide – exercise-induced ventricular tachycardia

ETT Guidelines, 2002

Exercise Testing for Diagnosis – Resting ECG Effects

- LBBB: ST depression is usual and unassociated with ischemia, even 10 mm
- RBBB nonspecific in V1 -V3, otherwise OK
- LVH nonspecific but no change in sensitivity, so a normal test reassures
- ST depression at rest (less than 1 mm)
  - Increased prevalence of CAD (30% vs 16%)
  - 2 mm additional or 1 mm downsloping, useful

ETT Guidelines, 2002

Exercise Testing for Diagnosis – Stress ECG Interpretation

- Upsloping ST depression – may be helpful if slowly upsloping (<1mv/sec), less specific than horizontal
- ST elevation if no infarction Q – rare (<1/1000) but significant and localizing
- R-wave amplitude – normally increases to HR of 130 then decreases – ignore, has no diagnostic value
- Heart rate - significant factor

ETT Guidelines, 2002

Exercise Testing for Diagnosis – Computer Processing

- Computer processing can produce false positive
- Always have unprocessed ECG data for comparison with any generated tracings
- Avoid simulation of raw data with averaged data
- Insert obvious breaks between averaged complexes

ETT Guidelines, 2002

Risk Assessment and Prognosis in Symptomatic Pts or Known Disease

- Class I – initial evaluation in known or suspected CAD
  - Follow up with significant change in clinical status
  - Low-risk UA after 8-12 h with no symptoms of AP or HF
  - Moderate risk UA after 2-3d with no symptoms of AP or HF
- Class IIa – Moderate risk UA with normal at presentation and after 6-12h biomarkers and no ECG change and no evidence of ischemia during observation

ETT Guidelines, 2002

Risk Assessment and Prognosis in Symptomatic Pts or Known Disease

- Class IIb - Uninterpretable ECG
  - Stable patient to guide treatment
- Class III - severe comorbidity affecting prognosis or candidacy for revascularization
  - High risk UA

ETT Guidelines, 2002

Prognostic Factors in CAD Patients

- Factors for current risk
  - LV function/damage
    - EF, ESV, MR,
    - Exercise duration
  - Severity of CAD
    - Anatomic extent
    - Collaterals
    - Evidence for ischemia
  - Coronary plaque event
  - Electrical instability
  - General health
- Factors for change in risk state
  - Factors predisposing to progression
    - Smoking
    - Hyperlipidemia
    - Diabetes mellitus
    - Hypertension
  - Other genetic or metabolic factors

ETT Guidelines, 2002, Table 14

Risk Assessment in Stable Angina - Considerations

- Exercise is test of choice for risk assessment
- Exercise-induced ST depression/elevation
  - time of onset (workload, HR, BP)
  - magnitude
  - number of leads
  - duration in recovery
- Hemodynamic: exercise capacity in METs
- Symptoms: angina onset, other symptoms

ETT Guidelines, 2002

Risk Assessment in Stable Angina - Information

- McNeer (Duke): high risk is ST depression at less than 6 min Bruce, low risk is over 9 min (1978)
- Weiner (CASS): ST depression in 3 min Bruce (12% of pop) mort of 5%/yr., but if over 6 min Bruce (34% of pop) had less than 1% mort/yr.
- Duke Treadmill score - need table
  - high risk (13% of pop) 5%/yr. mort
  - low risk (34% of pop) 0.5%/yr. mort

ETT Guidelines, 1997

Duke Treadmill Score

- No prior intervention
- Score = + Exercise time (min) - 5*(ST depression in mm) -4*(angina index)
- Angina index: 0 = no pain, 1 = nonlimiting pain, 2 = limiting pain
- High risk: ≦ -11
- Low risk: ≧ +5
- Consideration of age?

ETT Guidelines, 1997

Duke Treadmill Score

Angina index:
0 = no pain,
1 = nonlimiting pain
2 = limiting pain

- 613 outpatients with suspected coronary artery disease and ETT (1983-85)
- **Score = + Exercise time (Bruce, min) - 5*(ST depression in mm) -4*(angina index)**
- High risk: ≤ -11 (4% of patients) – 5% annual mortality
- Intermediate risk: 4 to -10 (34% of patients) – 1.25% annual mortality
- Low risk: ≥ +5 (62% of patients) – 0.25% annual mortality

Mark DB et al. N Engl J Med 1991;325:849.

Duke Treadmill Score

Angina index:
0 = no pain,
1 = nonlimiting pain
2 = limiting pain

- 2842 inpatients (37-60 yo, mean 49 yo with cath 1969-1981) with suspected CAD (39% had none), 5 year median f/u
- High risk: (13% of patients) – 5.6% annual mortality
- Intermediate risk: (53% of patients) – 1.8% annual mortality
- Low risk: (34% of patients) – 0.6% annual mortality
- Applicability good for inpatients or outpatients, men or women, but application to patients >65 yo less established

Mark DB et al. Ann Int Med 1987;106:793.

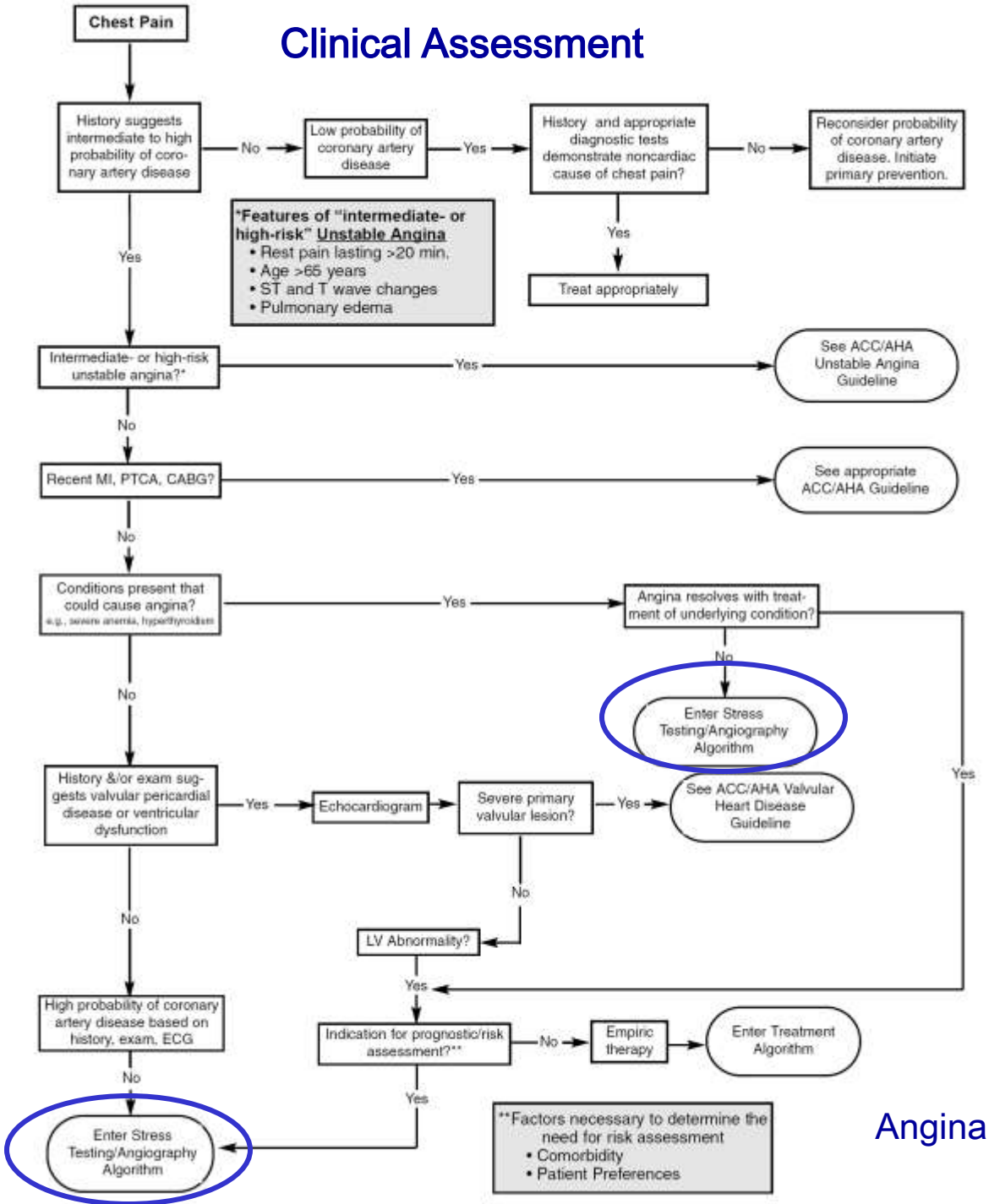
Outpatient vs Inpatient Duke Treadmill Score

Risk of Death	Inpatients		Outpatients	
	No.(%)	Survival	No.(%)	Survival
Low (≥5)	470 (34)	0.98	379 (62)	0.99
Moderate (-10 to +4)	795 (57)	0.92	211 (34)	0.95
High (≤-11)	129 (9)	0.71	23 (4)	0.79

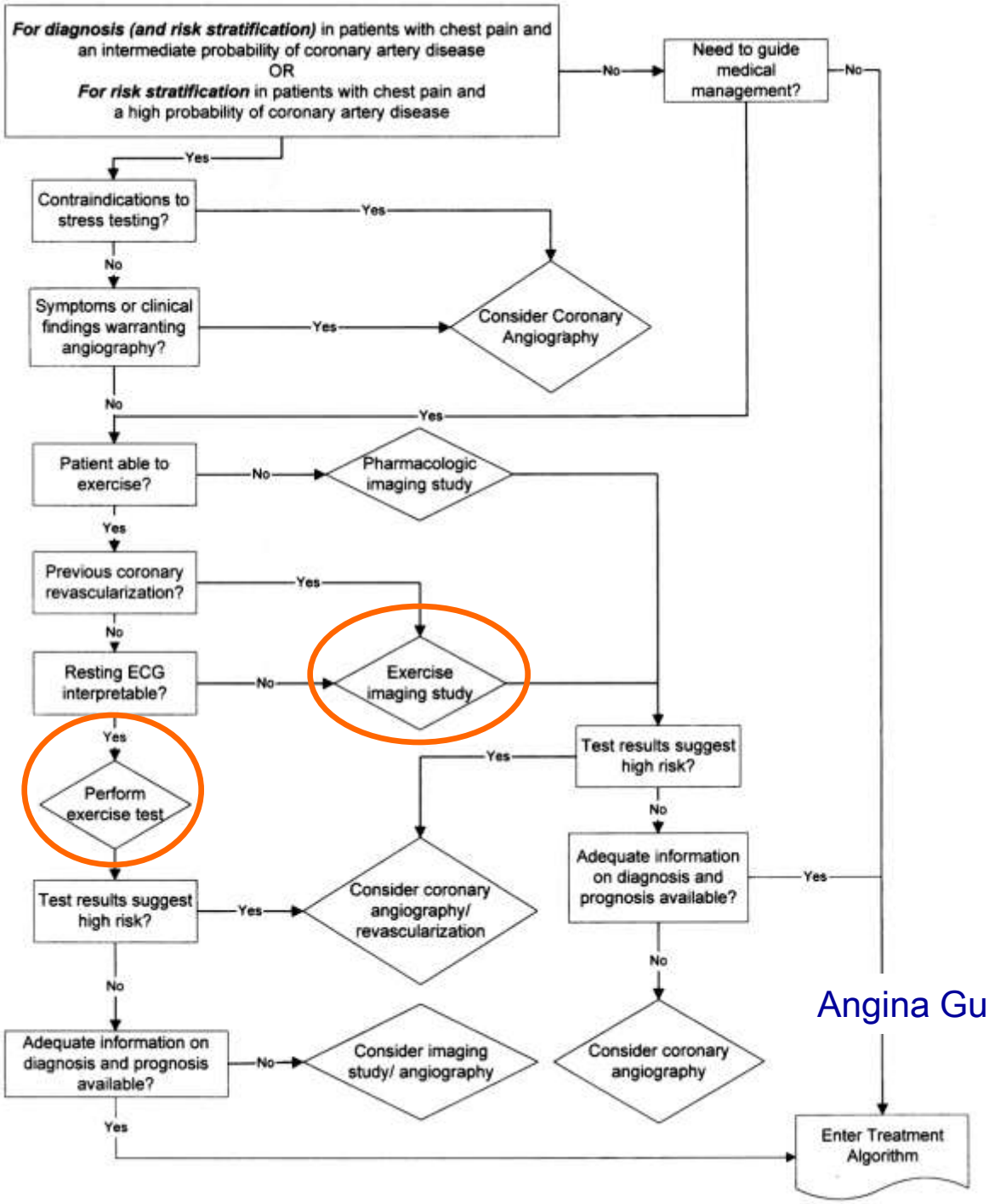
	Inpatients	Outpatients
Age	49 (43-55)	54 (45-62)
Prior MI (%)	29	11
Pathologic Q waves (%)	44	4
Ex duration >6 min (%)	54	77

Mark DB et al. N Engl J Med 1991;325:849.

Clinical Assessment



Angina Guidelines, 2002



Angina Guidelines, 1999, 2002

Risk Assessment in Stable Angina - Management

- If low risk, no advantage in further testing
- If intermediate risk, perfusion imaging appears to be of value
- If high risk, consider intervention
- In women, less data, treat the same
- Prediction for death is better than prediction of nonfatal myocardial infarction

ETT Guidelines, 1997

High Short-term Risk in Unstable Angina

- History:
  - Age over 75 years
  - Acceleration of symptoms in preceding 48 hours
  - Ongoing rest pain over 20 min
- Clinical:
  - pulmonary edema (probably ischemic)
  - new or worsening MR murmur
  - S3 or new/worsening rales,
  - hypotension, bradycardia, tachycardia
- ECG findings
  - Rest angina with dynamic ST depression >1/2 mm
  - BBB new or presumed new
  - Sustained VT
- Serum markers markedly elevated (TnT or TnI >0.1 ng/mg)

Unstable Angina Guidelines, 2000

Intermediate Short-term Risk in Unstable Angina

- No high risk feature
- History:
  - Prior MI, PVD, CVD, CABG, aspirin use
  - Prolonged (>20 min) rest angina, resolved with moderate or high likelihood of CAD
  - Rest angina, relieved with rest or sublingual NTG
  - Age >70 years
- ECG: T inversion > 0.2 mV or pathologic Q wave
- Serum marker: slightly elevated TnT (0.01 to 0.1) or TnI

Unstable Angina Guidelines, 2000

Low Short-term Risk in Unstable Angina

- No high or intermediate feature
- History:
  - New onset CCS class 3-4 angina in the past 2 wk with moderate or high likelihood of CAD
- ECG: normal or unchanged ECG during episode of discomfort
- Serum markers: normal

Unstable Angina Guidelines, 2000

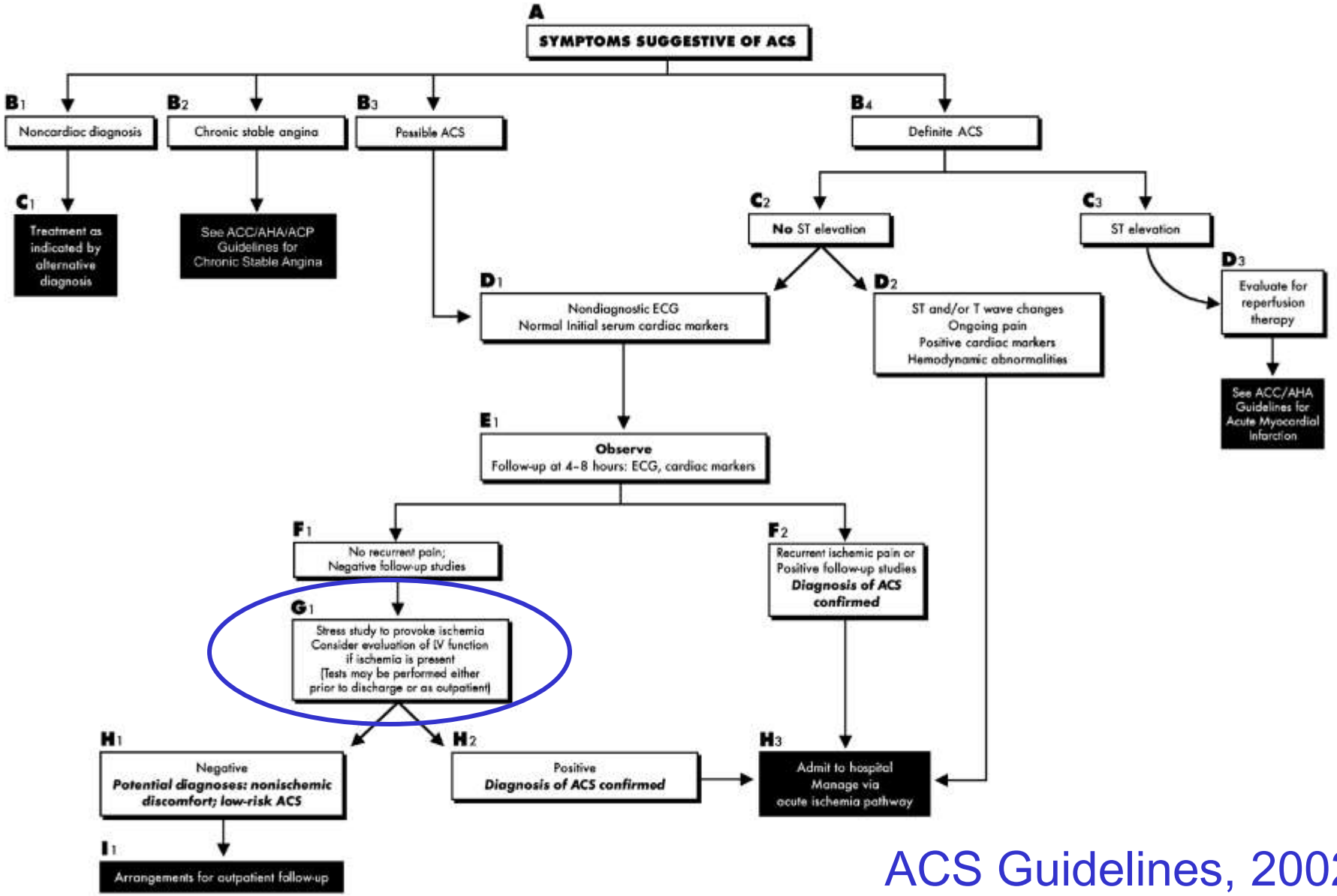
Clinical Risk in Unstable Angina: AHCPR Management

- High risk - Intensive care
- Intermediate risk - monitored hospital bed, should test unless catheterization is indicated, after 48 hr free of active ischemia or CHF
- Low risk - outpatient, should test within 72 hrs

Stress Test in Unstable Angina

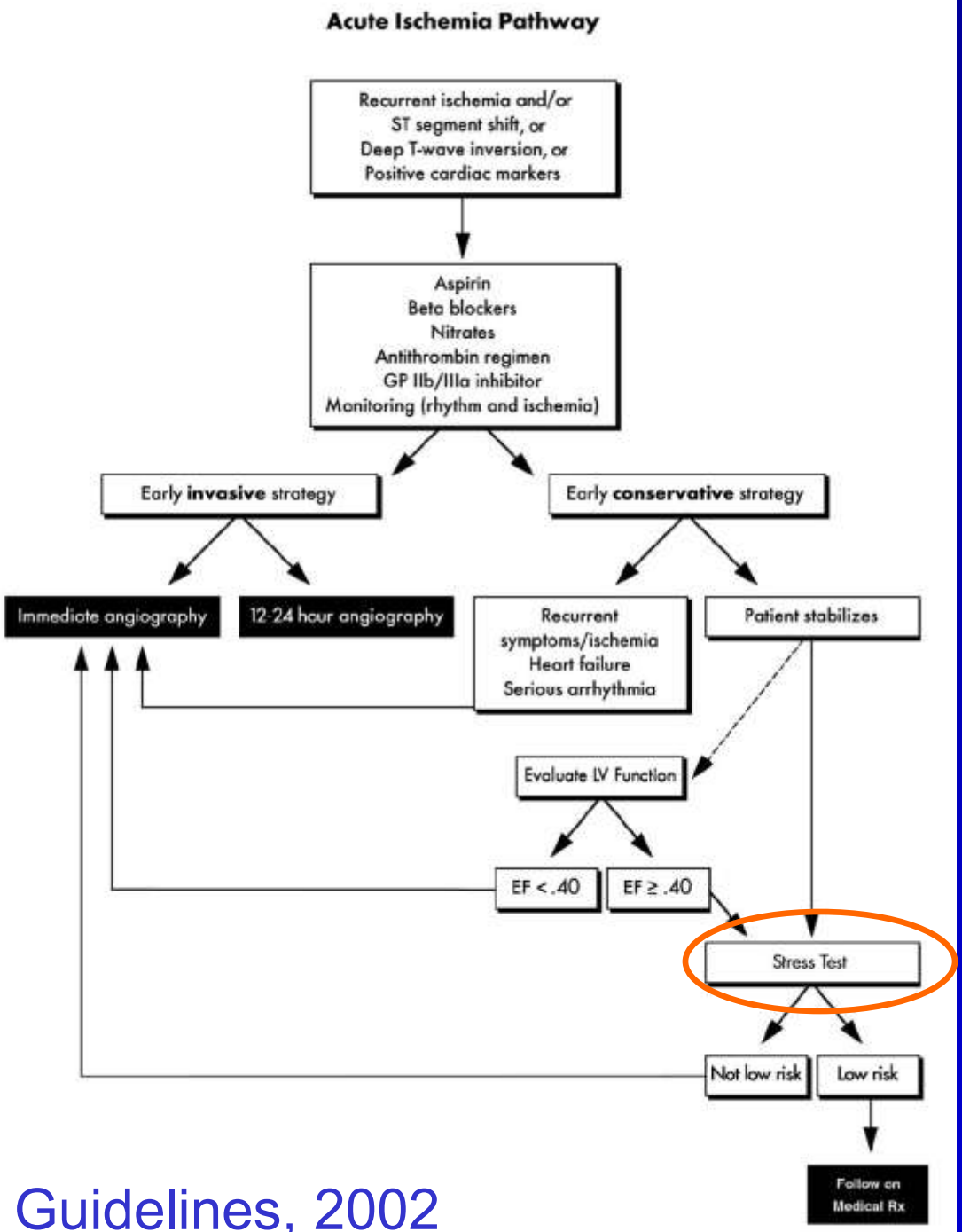
- Definite or possible ACS with normal initial and follow-up ECG and serum markers – if normal, may be managed as outpatient
- Low risk patient free of ischemia and CHF for 12-24 hours – low risk indicates medical management, high risk, catheterization
- Intermediate risk patient free of ischemia and CHF for 2-3 days

Unstable Angina Guidelines, 2000



ACS Guidelines, 2002

Figure 6. Algorithm for evaluation and management of patients suspected of having ACS. To facilitate interpretation of this algorithm and a more detailed discussion in the text, each box is assigned a letter code that reflects its level in the algorithm and a number that is allocated from left to right across the diagram on a given level.



Unstable Angina Guidelines, 2002

Stress Test in Unstable Angina

- Possible or definite ACS with nondiagnostic ECG and normal initial and follow-up serum markers and no recurrent pain; then manage via acute ischemia pathway if positive
- Option if recurrent ischemia or ST shift or positive serum markers, and stabilizes on medication (ASA, β-blocker, nitrate, LMWH or UFH, GP IIb/IIIa inhibitor), then catheterization if not low risk

Unstable Angina Guidelines, 2002

Risk in Unstable Angina: Exercise Test Result

- Similar prognostic factors as for stable angina
- Higher risk (Duke treadmill score)
  - poor exercise duration
  - inability to exercise
  - widespread or marked ST shift
  - angina during exercise
  - higher risk if LV dysfunction

Unstable Angina Guidelines, 2000

Risk in Unstable Angina: Use of Exercise Test Result

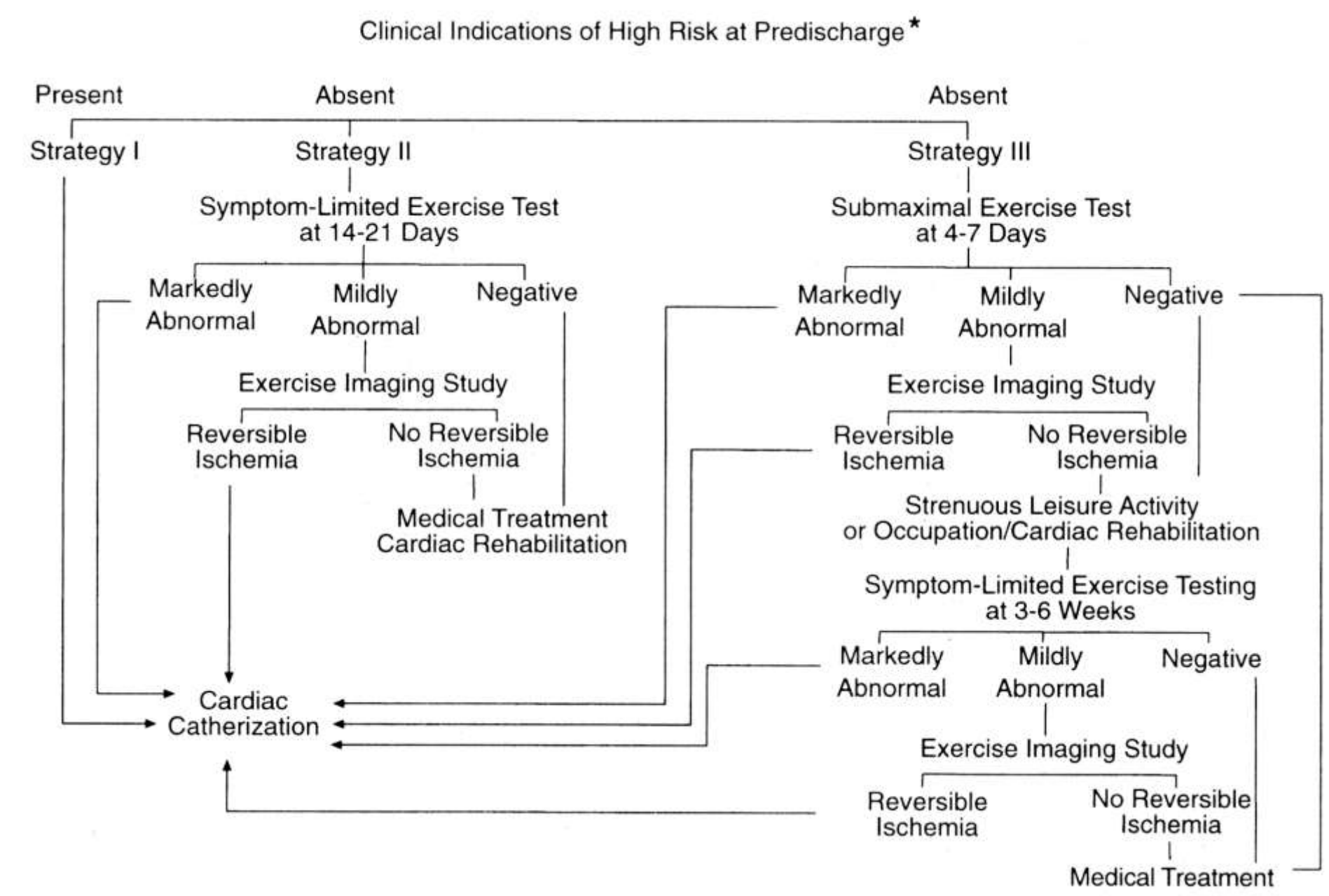
- Low risk result (predicted annual mortality <1%/yr.) - medical treatment
- High risk result (predicted annual mortality >4%/yr.) - usually catheterization
- Intermediate risk result (predicted annual mortality 2-3%/yr.) - additional testing--imaging study or catheterization

Unstable Angina Guidelines, 2002

Exercise Testing after Myocardial Infarction

- Class I - submaximal at 4-7 days, predischarge
  - maximal at 14-21 days if not done previously
  - maximal at 3-6 weeks if early test was submaximal
- Class IIa - after discharge and revascularization
- Class IIb - uninterpretable ECG, or periodic monitoring
- Class III - severe comorbidity

Treadmill Guidelines 2002



Treadmill Guidelines 2002

*High risk: ↓BP, CHF, recur CP, can't exercise

Exercise Testing after Myocardial Infarction: Poor Prognosis

- Exercise-induced ischemia
  - more than 2 mm
  - low exercise level
  - with controlled CHF
- Exercise capacity (<5 METs), or even more, inability to exercise
- Inability to increase SBP (<110 or <30 increase)

Treadmill Guidelines 2002

Exercise Testing after Myocardial Infarction: Usefulness

- Medical Decisions
- Activity counseling
  - Extrapolate from METs, as a guide
  - Most domestic chores are less than 5 METs
  - Most occupational activities require less than 5 METs
  - 15% of pop is heavy manual labor, require more info
- Cardiac rehabilitation

Treadmill Guidelines 2002

Exercise Testing Using Ventilatory Gas Analysis

- Class I - CHF considering transplantation
  - differentiation between cardiac and pulmonary limitation when clinically obscure
- Class IIa - exercise capacity when subjective assessment of maximal exercise is unreliable
- Class IIb - change in tolerance with therapy, or exercise prescription when tolerance is important endpoint
- Class III - Routine use to evaluate exercise capacity

Treadmill Guidelines 2002

Exercise Testing Using Ventilatory Gas Analysis - 2

- Measure oxygen uptake, carbon dioxide output, minute ventilation, and ventilatory/aerobic threshold (VAT)
- Best index of aerobic capacity: oxygen uptake which plateaus at maximal exercise
- Respiratory exchange ratio increases with exercise and maximal effort results in >1.0
- VAT : highly reproducible, abrupt increase in ventilation, associated with increase in lactate

Treadmill Guidelines 2002

Exercise Testing Using Ventilatory Gas Analysis - 3

Intensity	% Maximum O2 deliv
Very Light	<25
Light	25-44
Moderate	45-59
Hard	60-84
Very hard	>85
Maximal	100

Exercise Testing Using Ventilatory Gas Analysis - 4

Class	Impairment	Peak O2 (mL/kg/min)	VAT (mL/kg/min)
A	None-mild	>20	>14
B	Mild-mod	16-20	11-14
C	Mod-severe	10-16	8-11
D	Severe	<10	<8

Treadmill Guidelines 2002

Exercise Testing Using Ventilatory Gas Analysis - 5

Category for Transplant	Peak O2 Uptake (mL/kg/min)
Accepted indication	<10
Probable indication	<14
Inadequate indication	>15

Exercise Testing: Special groups

- Women
- Elderly
- Asymptomatic persons
- Valvular disease
- Before and after Revascularization
- Assessment of Rhythm disorders

Treadmill Guidelines 2002

Exercise Testing in Women

- ECG response may be different in women
- Use of non-ECG end points
- Generally more difficult than in men
  - different physiology
  - body habitus
  - coronary physiology
  - prevalence of CAD
- Currently insufficient data for routine imaging

Exercise Testing in the Elderly

- Diagnosed CAD in over 1% population over 75 yr.
- Silent ischemia estimated in 15% of 80-year-olds
- Musculoskeletal problems are important limit
- Chronotropic incompetence and hypotension are ominous
- ST depression is less specific, more sensitive

Treadmill Guidelines 2002

Exercise Testing in Asymptomatic Persons

- Class IIa – Asymptomatic persons with DM who plan to start vigorous exercise
- Class IIb (Class I - NONE)
  - Persons with multiple risk factors
    - Chol >240, Htn, Smoking, diabetes, fam hx <60 yr.
    - At least moderate Framingham risk
  - Men over 45 and women over 55
    - Starting vigorous exercise (esp if sedentary)
    - Occupation of public safety concern
    - High risk from other diseases (eg, renal failure)
- Class III - routine screening of men or women

Treadmill Guidelines 2002

Exercise Testing Before and After Revascularization

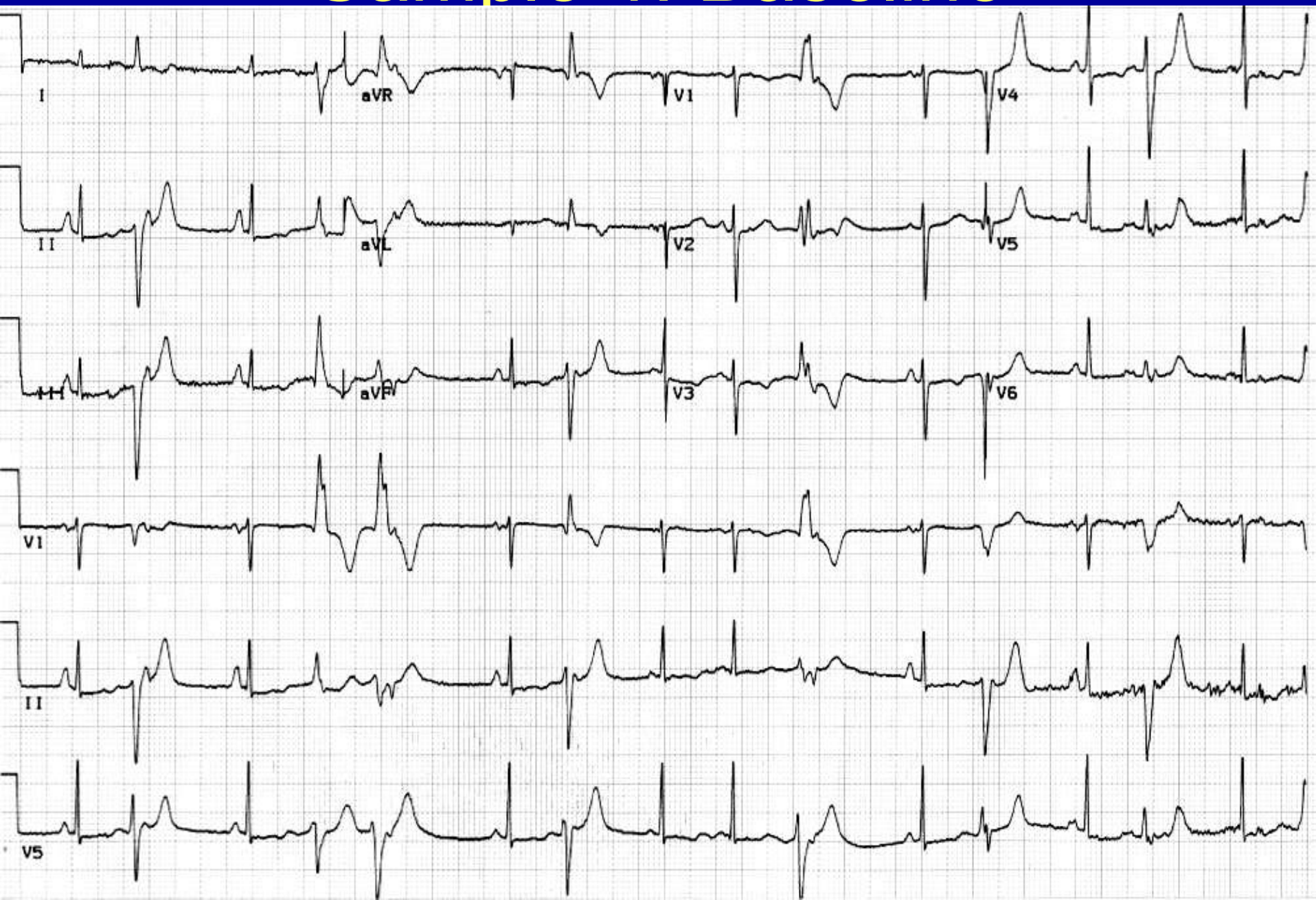
- Class I - show ischemia pre procedure; evaluate symptoms that suggest ischemia after procedure
- Class IIa - after discharge for rehab or Ex Rx
- Class IIb - detect restenosis, aSx in first 12 months; periodic monitoring of selected high risk pts
- Class III - localiz of isch to direct intervention; routine periodic monitoring post intervention

Treadmill Guidelines 2002

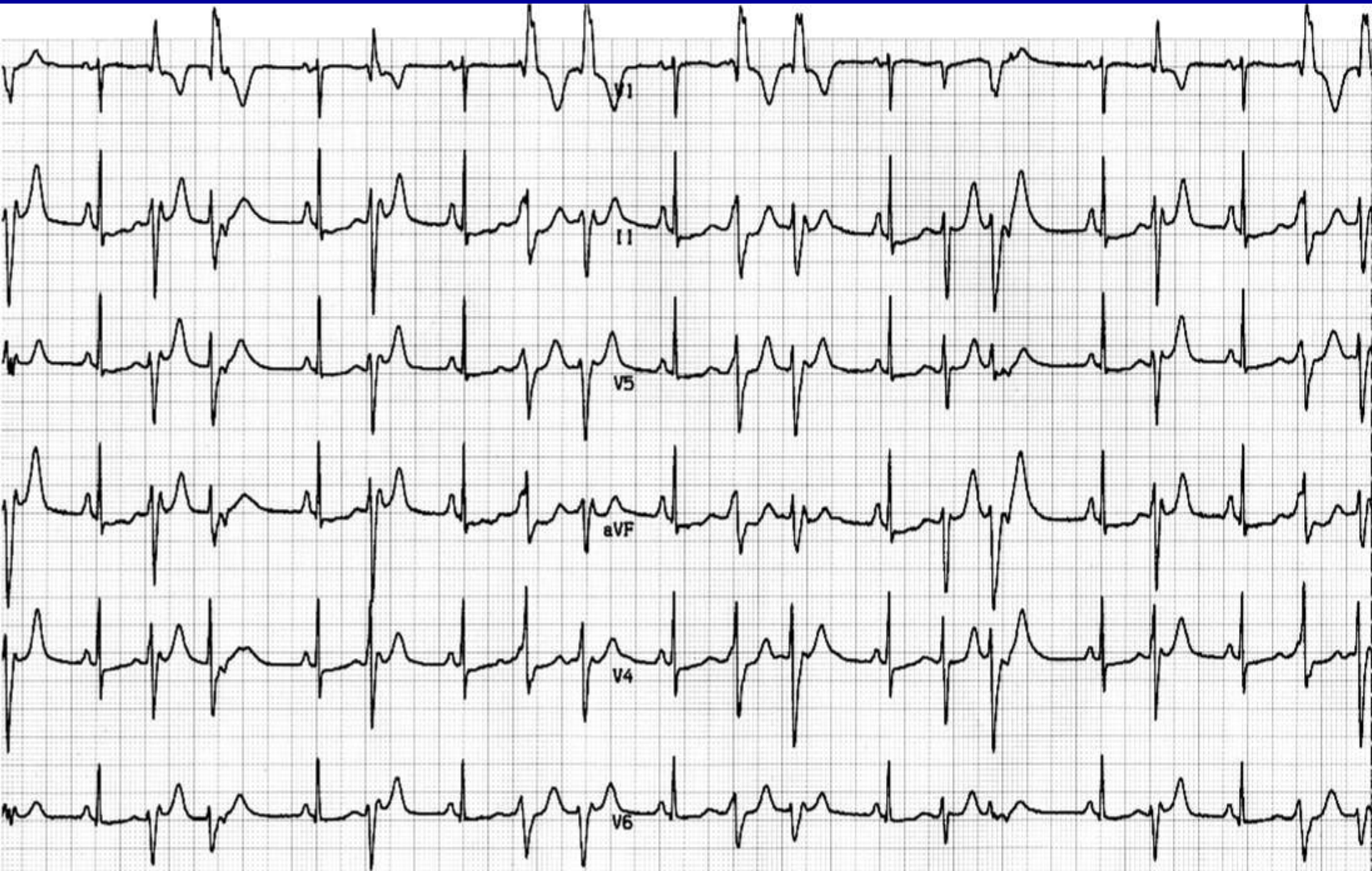
Exercise Testing - Summary

- Exercise testing in properly selected patients and clinical settings is useful in diagnosis, prognosis and guiding therapy
- The limitations of exercise testing are important considerations in its proper use
- Exercise testing is frequently the initial test of choice in managing patients with known or suspected coronary artery disease

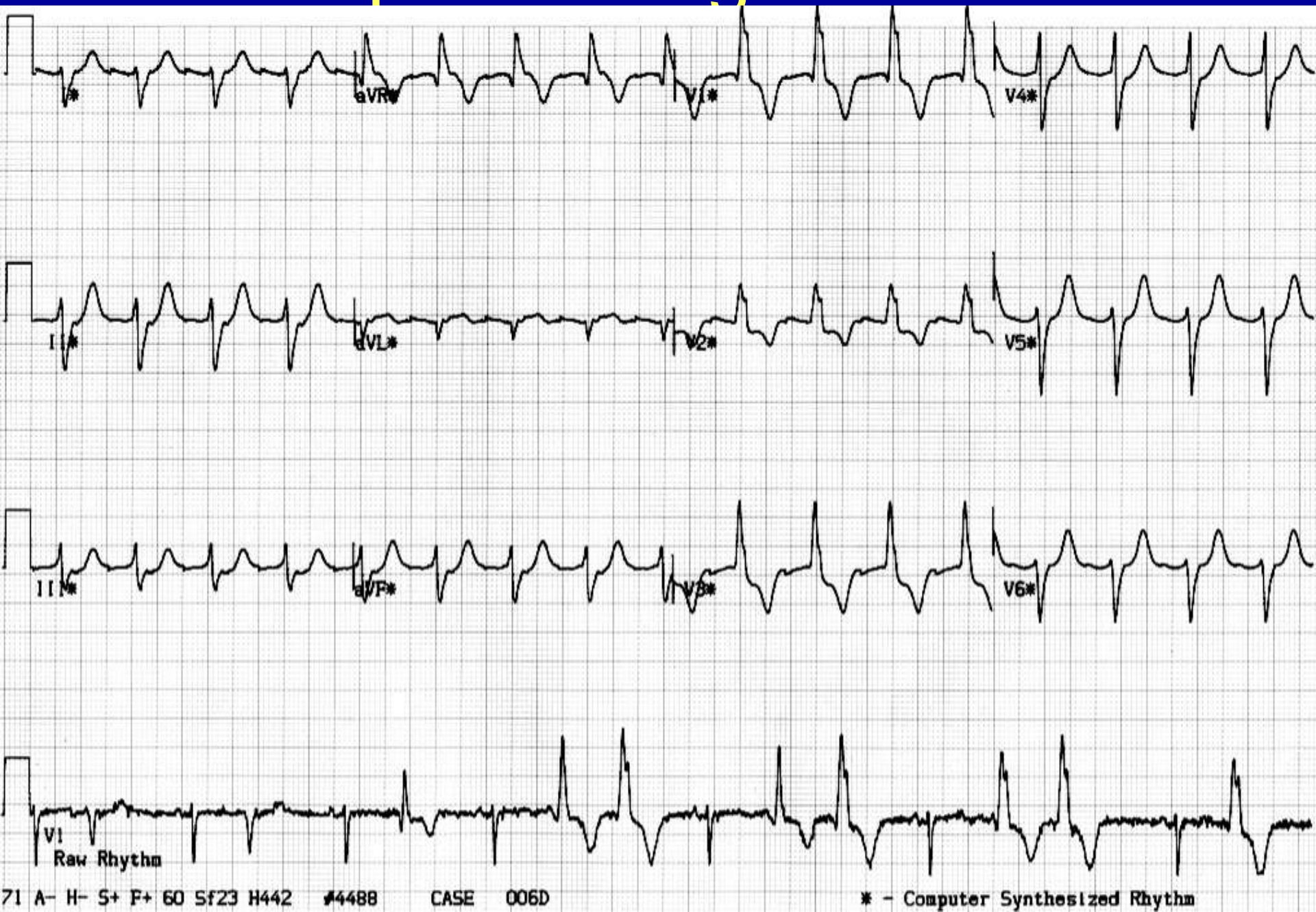
Sample 1: Baseline



Sample 1: Baseline part 2



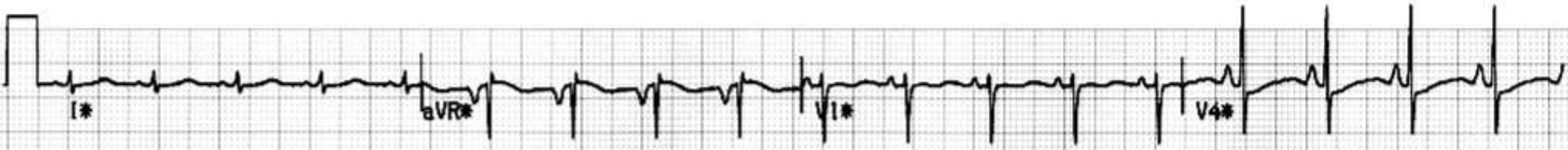
Sample 1: Stage 1 PThall



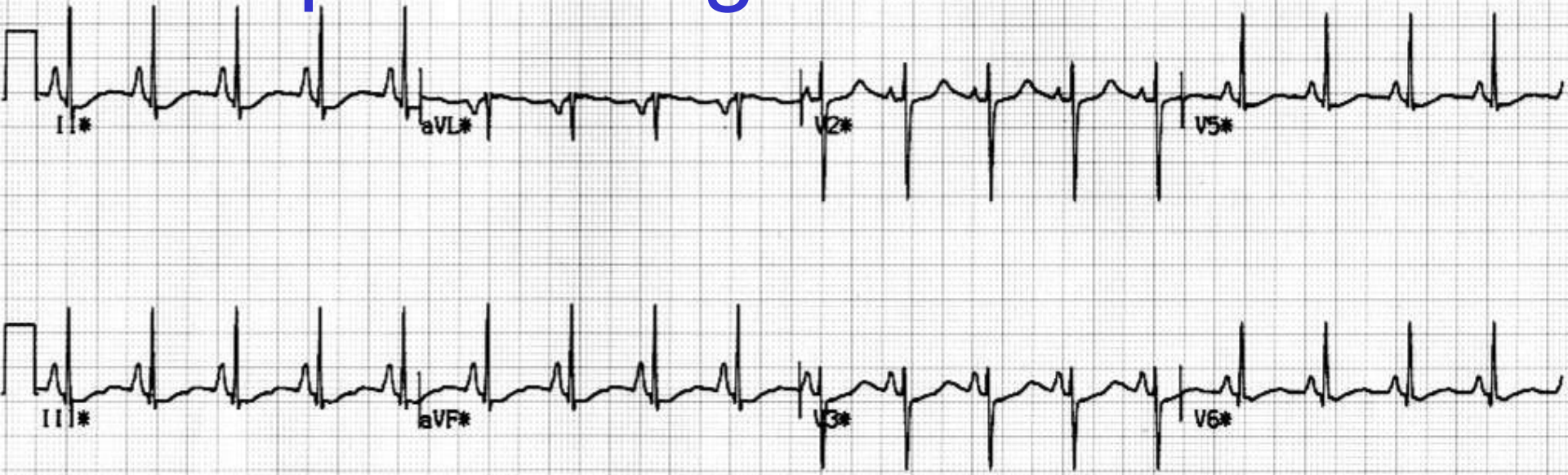
Sample 1: Stage 3 PThall

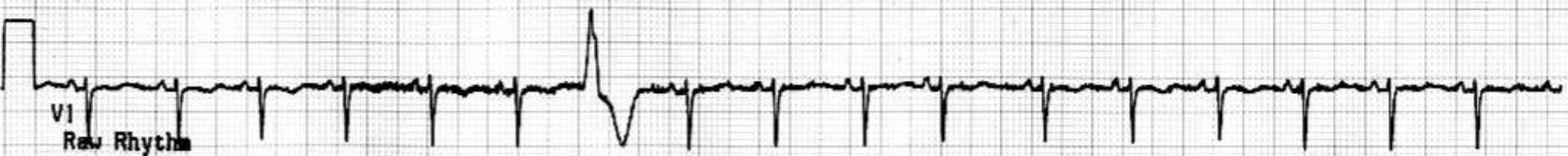
RELEARN at EXERCISE 08:07

III	-0.5	V3	-0.2
aVR	0.3	V4	-0.2
aVL	0.3	V5	-0.2
aVF	-0.5	V6	-0.1



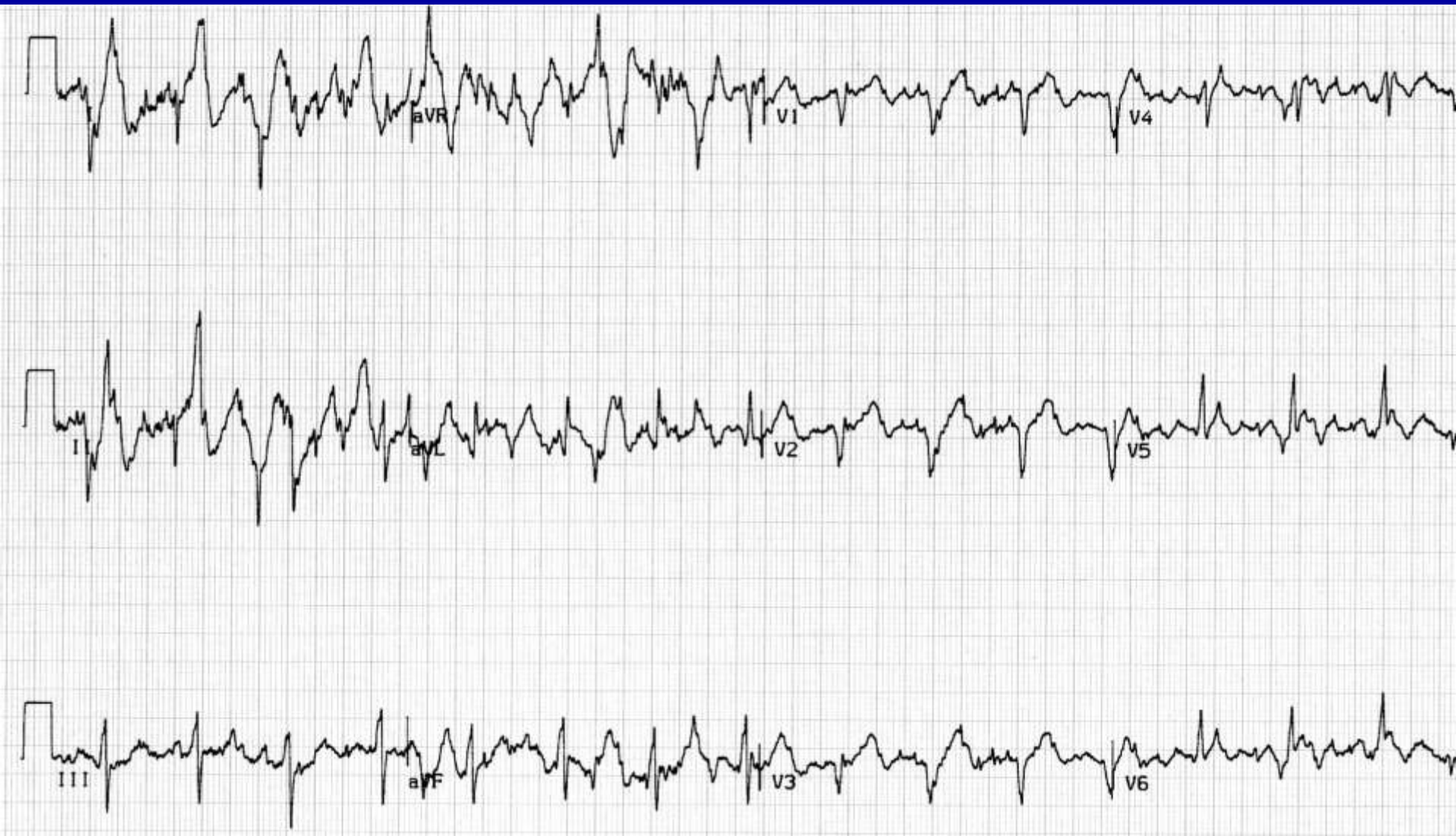
Sample 1: Stage 3 Plus P Thall





Sample 2: Baseline

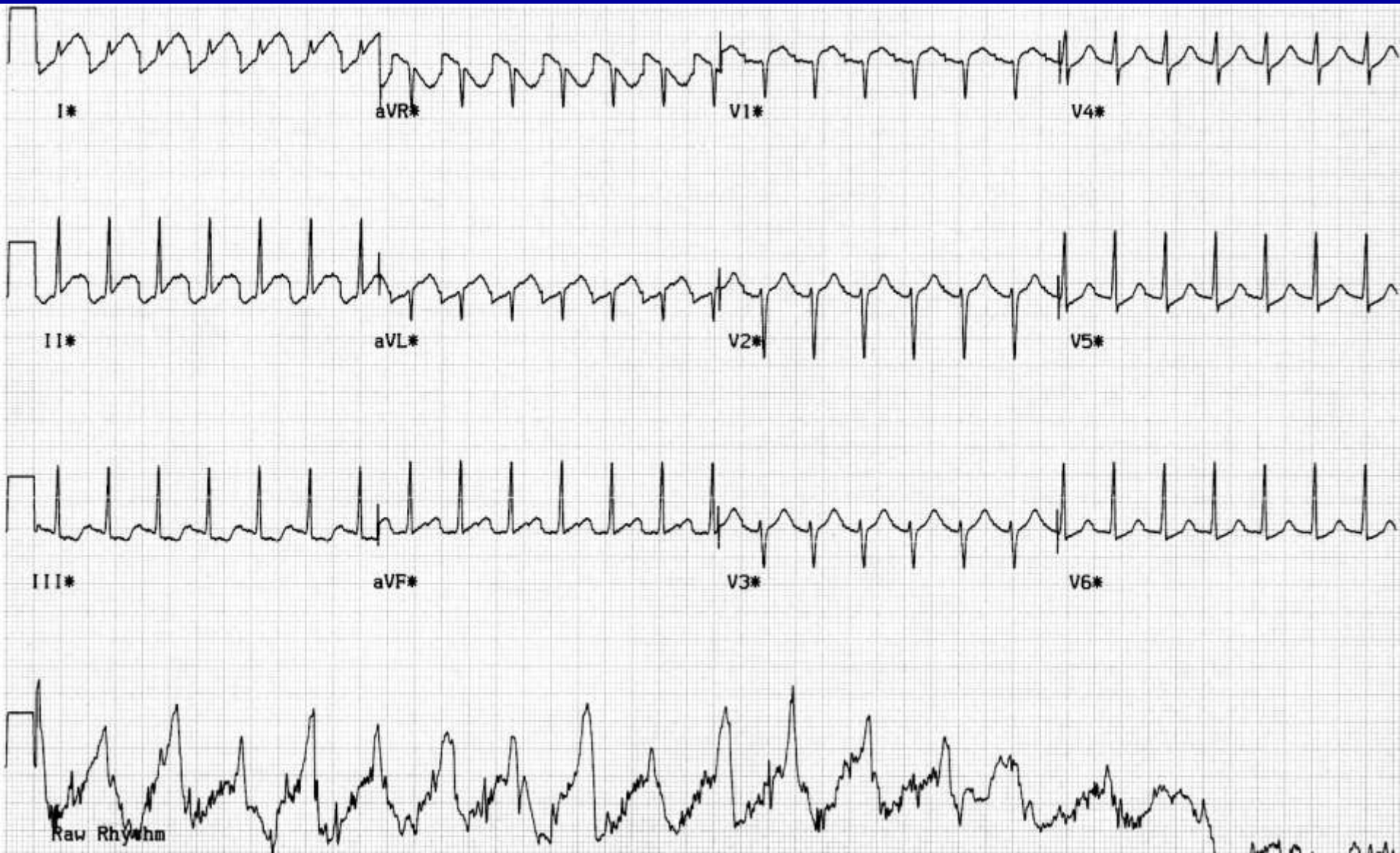
Sample 2: Stage 1



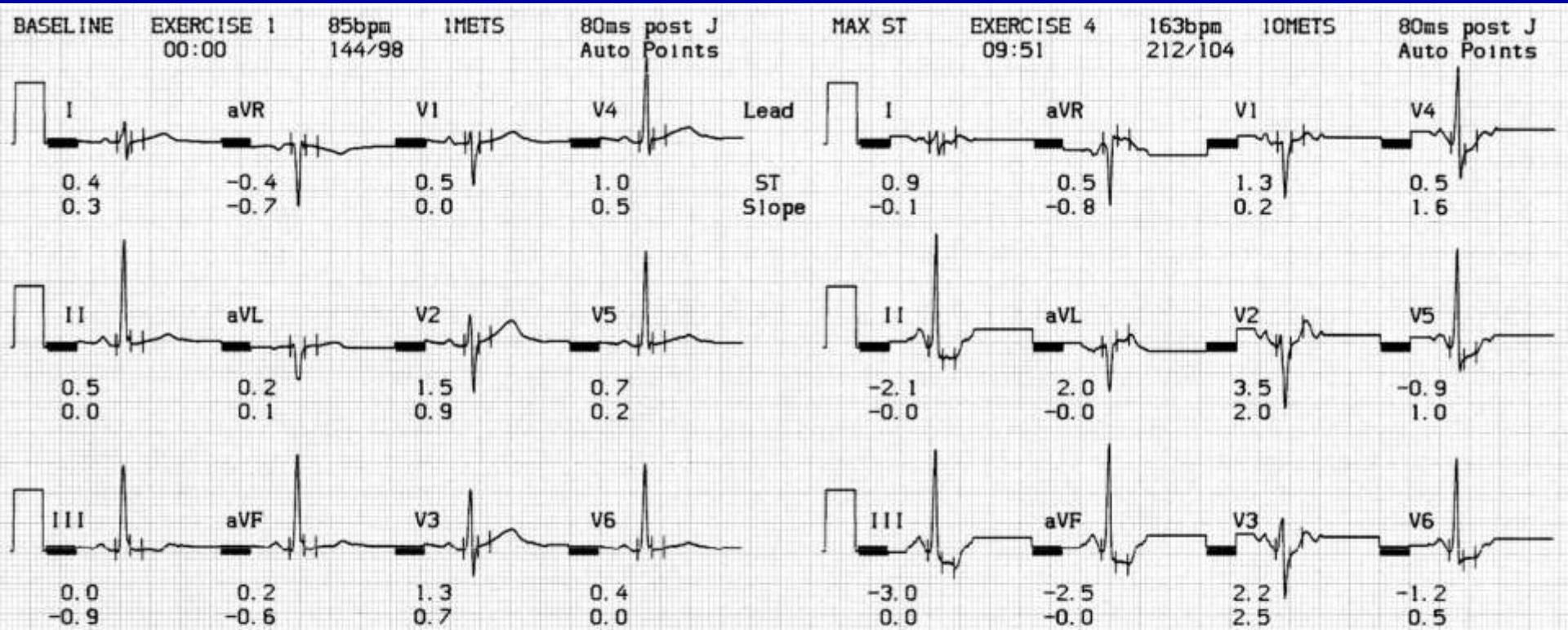
Sample 2: Stage 1b

Sample 2: Stage 2

Sample 3: More artifact



Sample 4: Atrial repolarization



Impressions:

BASELINE ECG NSR 64. NSST INF
NO CP OR ANGINAL EQUIVALENT
1 MM ST DEPRESION INF AT END STAGE 3 (HR 153. BP 212)
RESOLVE BY 1 MIN INTO RECOVERY
NO DYSRYTHMIA
IMP- CLINICALLY NEG. ELECTRICALLY POS FBETT WITH GOOD EXERCISE TOLERANCE

Other artifacts of averaging:

- Atrial fibrillation becomes suddenly regular