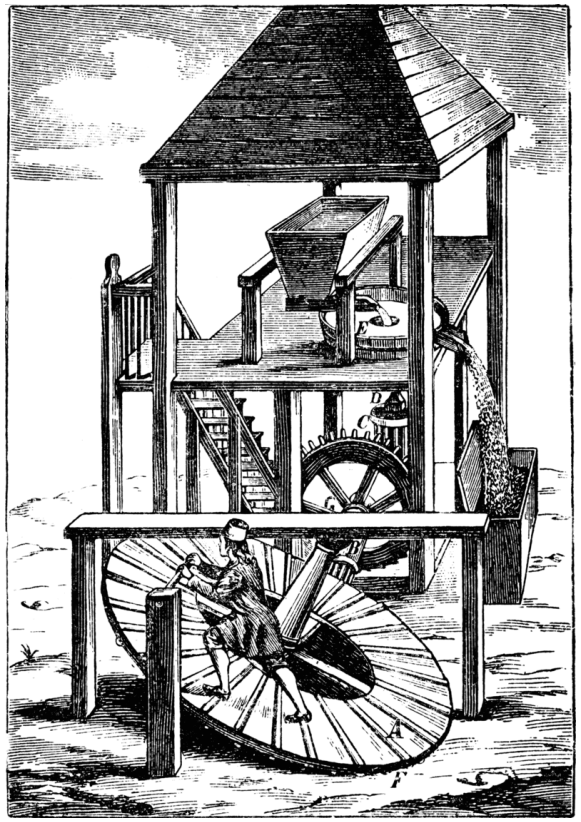
Treadmill test의 적응증과 해석

경희의대 이정명

Treadmill



- Roman Empire around 1st century: for grinding grain
- Penal treadmill, 19th century, Britain.

- Exercise induced ST depression: 1846 Einthoven
- Modern medical treadmill: 1952 Robert Bruce
- Widely used for diagnosis of ischemic heart disease

Indication(1) – CAD diagnosis

Class I

1. 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 (Table 4), based on gender, age, and symptoms (specific exceptions are noted under Classes II and III below).

Mean sensitivity 68%
Mean specificity 77%

Test	Sensitivity	Specificity
Exercise ECG treadmill[1]	68%	77%
Exercise Echo treadmill[2]	86%	81%
Dobutamine Echo[2]	~85%	~85%
Exercise nuclear treadmill[3]	87%	73%
Pharmacologic nuclear[3]	89%	75%
Coronary CTA[4]	**94%**	**83%**

1.ACC/AHA 2002 Guideline Update for Exercise Testing
2.ACC/AHA/ASE 2003 Guideline Update for the Application of Echocardiography
3.ACC/AHA/ASNC Guidelines for the Clinical Use of Cardiac Radionuclide Imaging
4.ACCURACY study

Table 4. Pretest Probability of Coronary Artery Disease by Age, Gender, and Symptoms*

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

Class III

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

1997 AHA guideline and 2002 update

Indication(2) – with known or suspected CAD or post MI

Class I

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 (see Table 17) 8 to 12 hours after presentation who have been free of active ischemic or heart failure symptoms. *(Level of Evidence: B)*

4. Intermediate-risk unstable angina patients (see Table 17) 2 to 3 days after presentation who have been free of active ischemic or heart failure symptoms. *(Level of Evidence: B)*

Class I

1. Before discharge for prognostic assessment, activity prescription, evaluation of medical therapy (submaximal at about 4 to 7 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

1. After discharge for activity counseling and/or exercise training as part of cardiac rehabilitation in patients who have undergone coronary revascularization.

Indication (3) – asymptomatic person without known CAD

Class I 1997 AHA guideline and 2002 update

1. None.

Class IIb

1. Evaluation of persons with multiple risk factors.*

Class III

1. Routine screening of asymptomatic men or women.

Figure 2. Clinical Summary: Screening for Cardiovascular Disease Risk With Electrocardiography

Population	Adults at low risk of CVD events	Adults at intermediate or high risk of CVD events
Recommendation	Do not screen with resting or exercise ECG. Grade: D	No recommendation. Grade: I (insufficient evidence)

US Preventive Services Task Force *JAMA*. 2018;319(22):2308-2314. doi:10.1001/jama.2018.6848

Indication(4) - arrhythmia

Class I

1. Identification of appropriate settings in patients with rate-adaptive pacemakers.

Class IIa

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

1. Investigation of isolated ventricular ectopic beats in middle-aged patients without other evidence of CAD.

Class III

1. Investigation of isolated ectopic beats in young patients.

Evluation for..

Exercise induced arrhythmia/symptom

Asymptomatic WPW

Chronotropic incompetence, SSS

AV block (ex. 2 to 1 block)

Recommendations for Management of Asymptomatic Patients With Pre-Excitation

COR	LOE	Recommendations
I	B-NR [SR] C-LD [SR]	1. In asymptomatic patients with pre-excitation, the findings of abrupt loss of conduction over a manifest pathway during exercise testing in sinus rhythm[294–297] *(Level of Evidence: B-NR)* [SR] or intermittent loss of pre-excitation during ECG or ambulatory monitoring[297] *(Level of Evidence: C-LD)* [SR] are useful to identify patients at low risk of rapid conduction over the pathway.

Exercise test		
Exercise testing is recommended in patients who experience symptoms suspicious of brady-cardia during or immediately after exertion.	I	C
In patients with suspected chronotropic incom-petence, exercise testing should be considered to confirm the diagnosis.	IIa	B
In patients with intra-ventricular conduction dis-ease or AVB of unknown level, exercise testing may be considered to expose infranodal block.	IIb	C

Most commonly used criteria for chronotropic incompetence:

< 80% of age predicted maximal heart rate (220-age)

In patients presenting with exercise intolerance in whom chrono-tropic incompetence has been identified, the usefulness of cardiac pacing is uncertain, and the decision to implant a pacemaker in such patients should be made on a case by case basis.

Permanent AF with chronotropic incompetence (due to intermittent or complete AV block) correlated with symptoms is an indication for pacing

2021 ESC guideline

Absolute Contraindications

- Acute myocardial infarction (MI), within 2 days
- Ongoing unstable angina
- Uncontrolled cardiac arrhythmia with hemodynamic
- compromise
- Active endocarditis
- Symptomatic severe aortic stenosis
- Decompensated heart failure
- Acute pulmonary embolism, pulmonary infarction, or deep vein thrombosis
- Acute myocarditis or pericarditis
- Acute aortic dissection
- Physical disability that precludes safe and adequate testing

Protocols

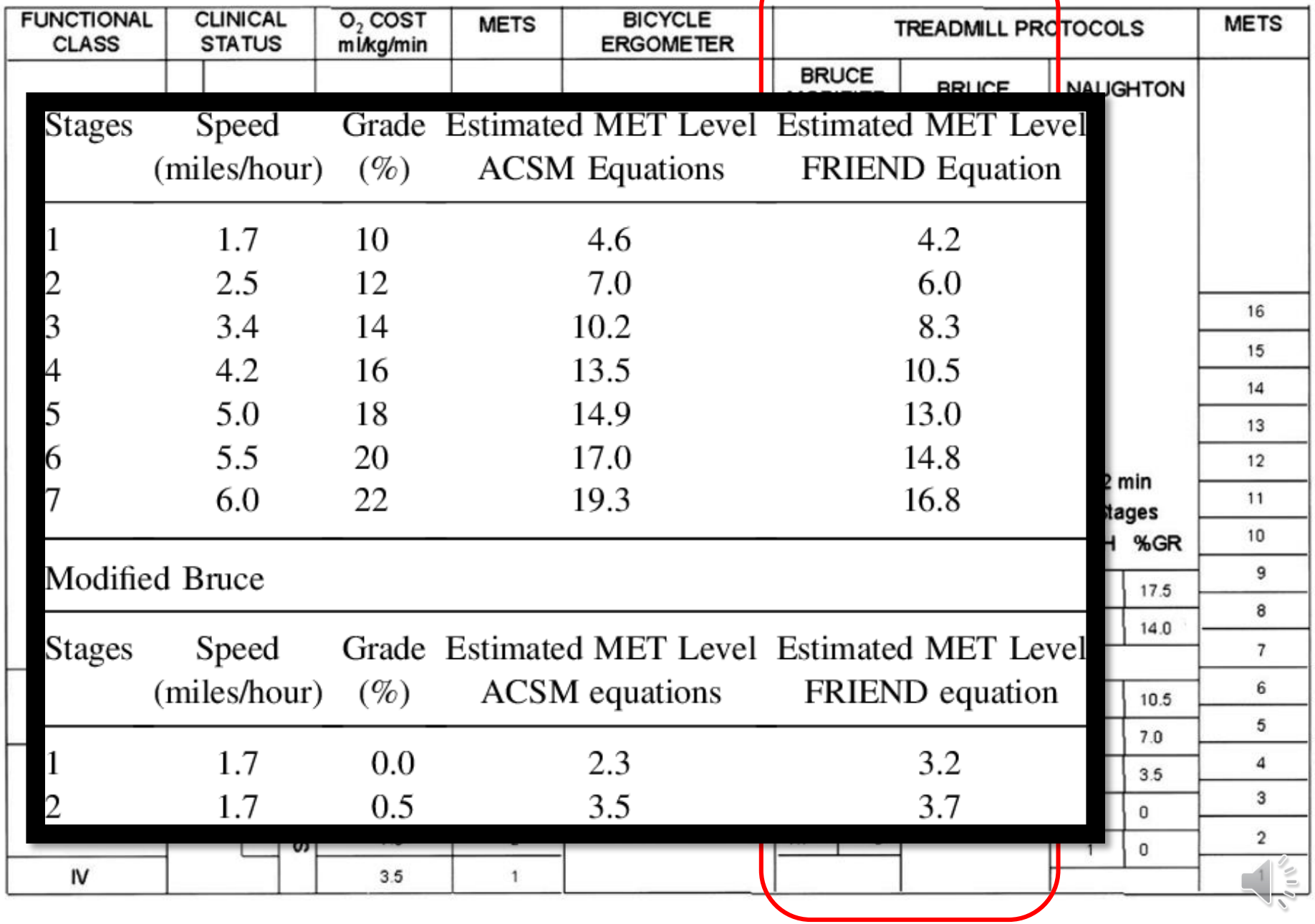
- **Bruce protocol**
- Modified Bruce protocol
  - Stage 0 and ½
- RAMP protocol
- Etc

- MET
- Metabolic Equivalent of Task
- 1 MET=quiet sitting
- O2 consumption: 3.5 ml/kg/min
- 3 METS=walking, 3.0 mph (4.8 km/h)
- 6 METS=aerobic dancing, medium effort
- 10 METS=foot ball

Stages	Speed (miles/hour)	Grade (%)	Estimated MET Level ACSM Equations	Estimated MET Level FRIEND Equation
1	1.7	10	4.6	4.2
2	2.5	12	7.0	6.0
3	3.4	14	10.2	8.3
4	4.2	16	13.5	10.5
5	5.0	18	14.9	13.0
6	5.5	20	17.0	14.8
7	6.0	22	19.3	16.8

Modified Bruce

Stages	Speed (miles/hour)	Grade (%)	Estimated MET Level ACSM equations	Estimated MET Level FRIEND equation
1	1.7	0.0	2.3	3.2
2	1.7	0.5	3.5	3.7

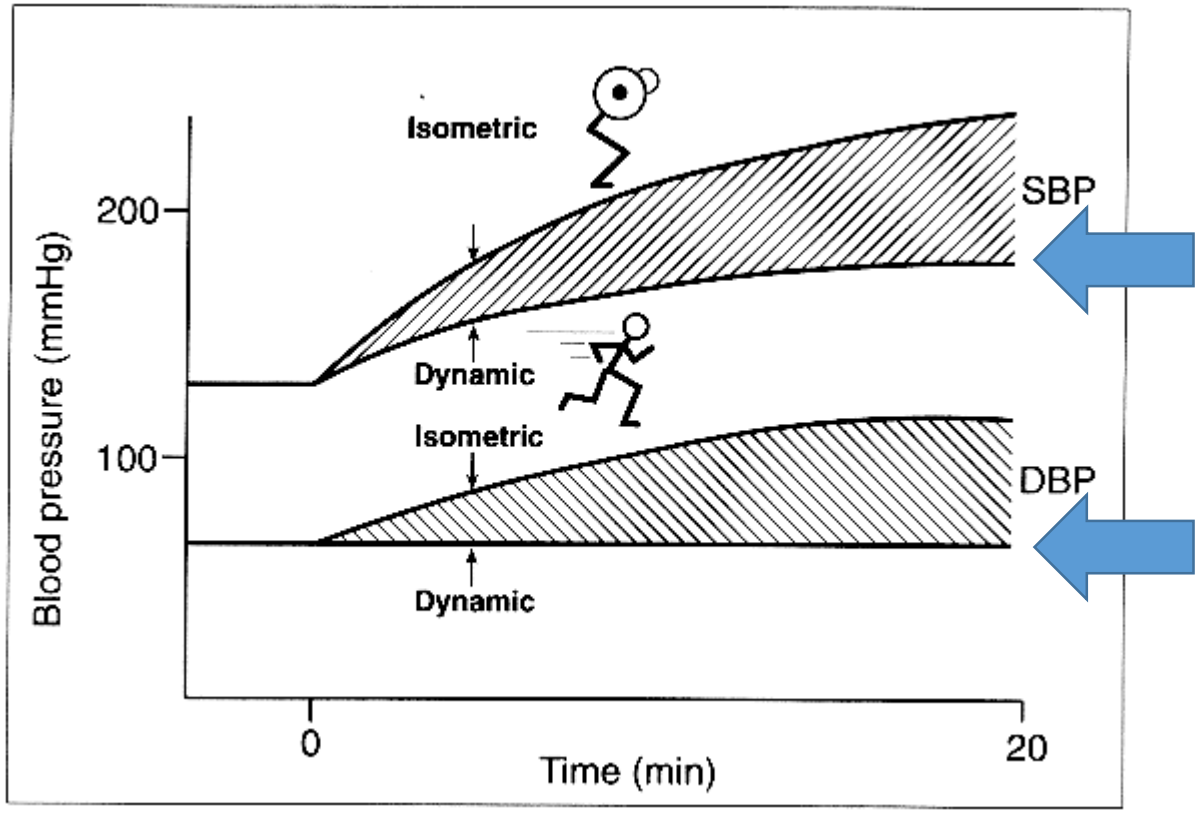


Normal Heart rate response during exercise

- Maximum predicted HR=220–age in years
  - Most commonly used estimation
  - High degree of variability : ±12 bpm
- A normal increase in HR during exercise is ≈10 bpm per metabolic equivalent (MET)
- The decline of HR After exercise generally exhibits a rapid fall during the first 30 seconds after exercise

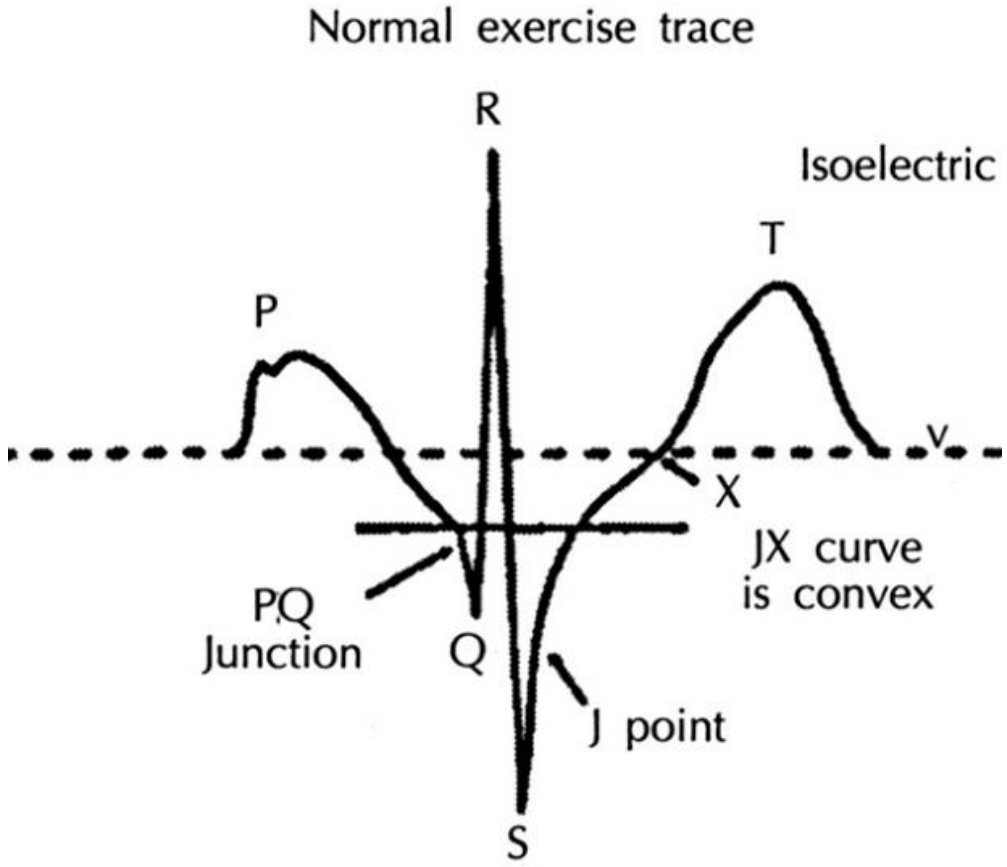
Normal BP response during TMT

- SBP rises with increasing dynamic work as a result of increasing cardiac output,
- DBP usually remains about the same or is moderately decreased because of vasodilatation of the vascular bed.
- The average rise in systolic blood pressure during a progressive exercise test is about 10 mm Hg/MET



Normal ECG change during exercise

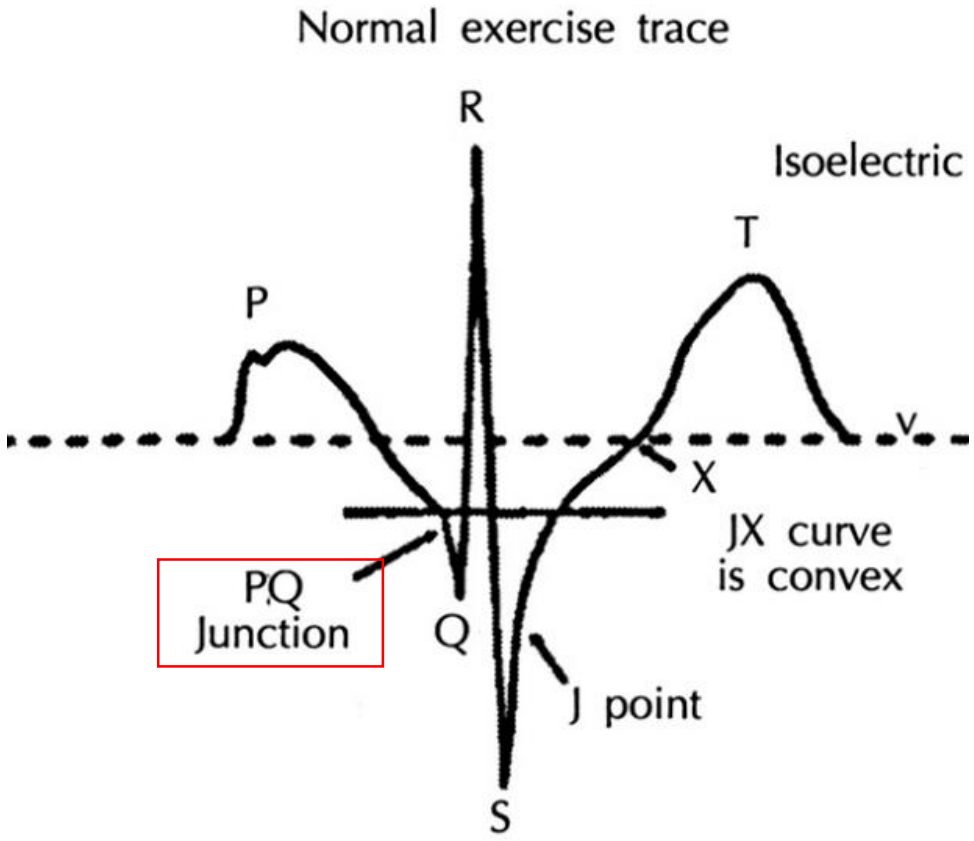
- P wave: magnitude increase, duration no significant change.
- PR: shortens, slopes downward
- QRS: duration decrease, septal Q in lateral lead increase, R decrease/S increase in inferior leads
- J point: depression
- ST: upsloping ST depression(20%)
- T wave: amplitude decrease → increase
- U wave: no change.
- QT: absolute QT decrease



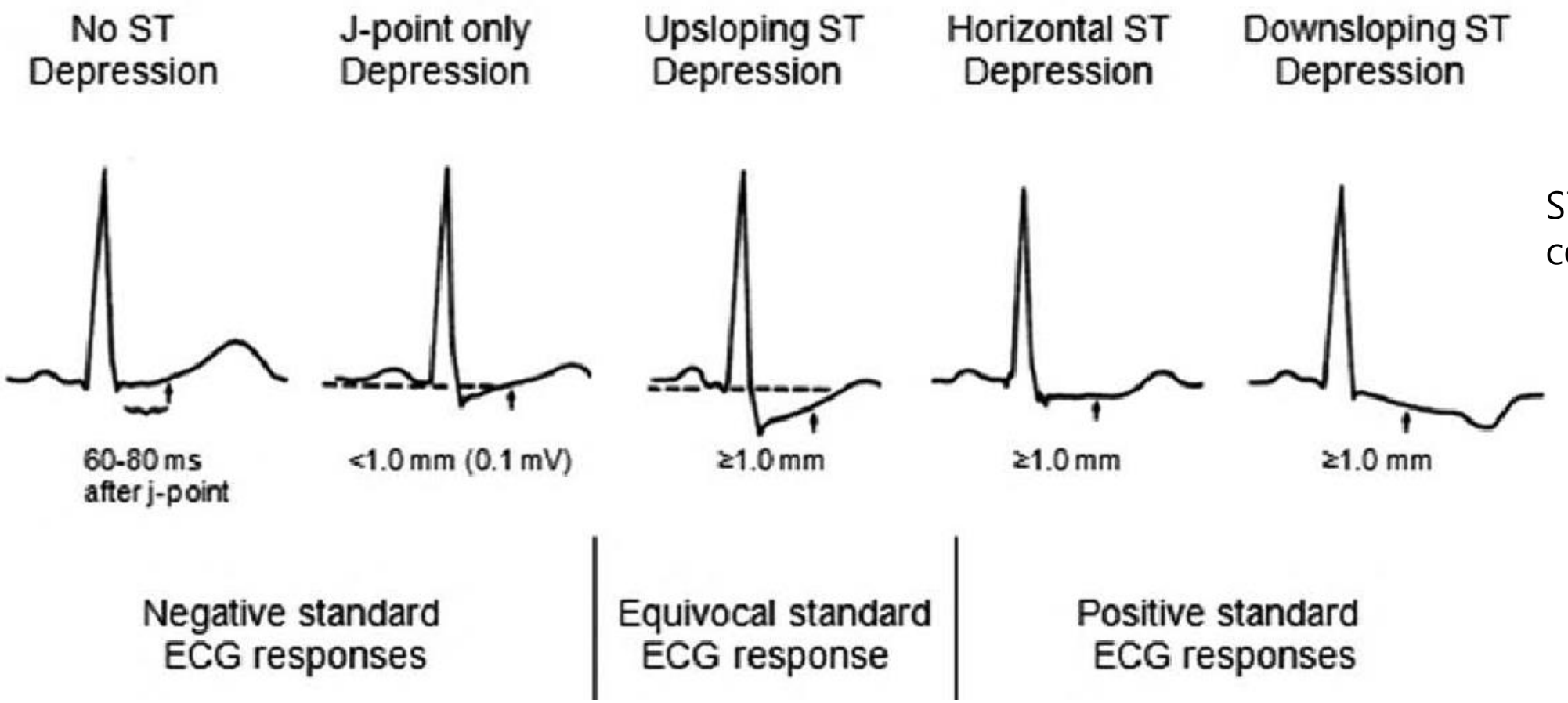
Korean Circulation J 2000;30(5):653-674

ST change

- The ST level is measured relative to the end of the PR segment (the P–Q junction) because the T(U)–P segment during exercise is difficult or impossible to measure when HRs are fast.
- Three or more consecutive beats in the same lead with a stable baseline should be identified and the average magnitude and tangent direction of displacement at 60 to 80 ms after the J point determined



ST SEGMENT DEPRESSION DURING EXERCISE

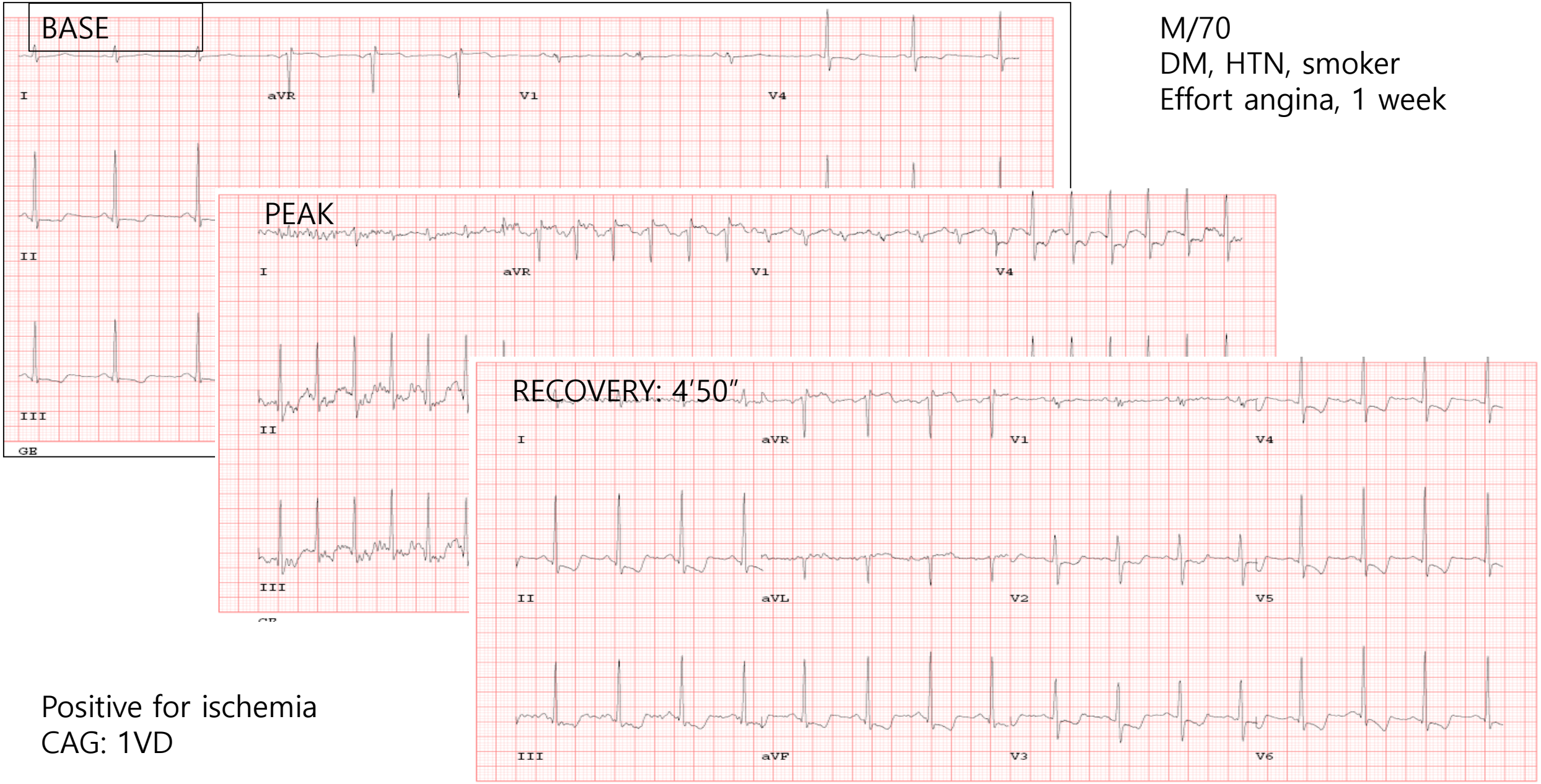


ST depression in 3 consecutive beats

In the presence of resting ST-segment elevation at 60 to 80 ms after the J point because of early repolarization, only ST-segment changes below the P-Q baseline should be used for analysis

- Interpretation in pts with Baseline ST depression?
  - When modest resting ST depression is present on the upright control ECG before exercise, only additional ST depression during exercise is measured for analysis.

- Interpretation in pts with Baseline ST elevation(early repol.)?
  - In the presence of resting ST-segment elevation at 60 to 80 ms after the J point because of early repolarization, only ST-segment changes below the P-Q baseline should be used for analysis



M/70
DM, HTN, smoker
Effort angina, 1 week

Positive for ischemia
CAG: 1VD

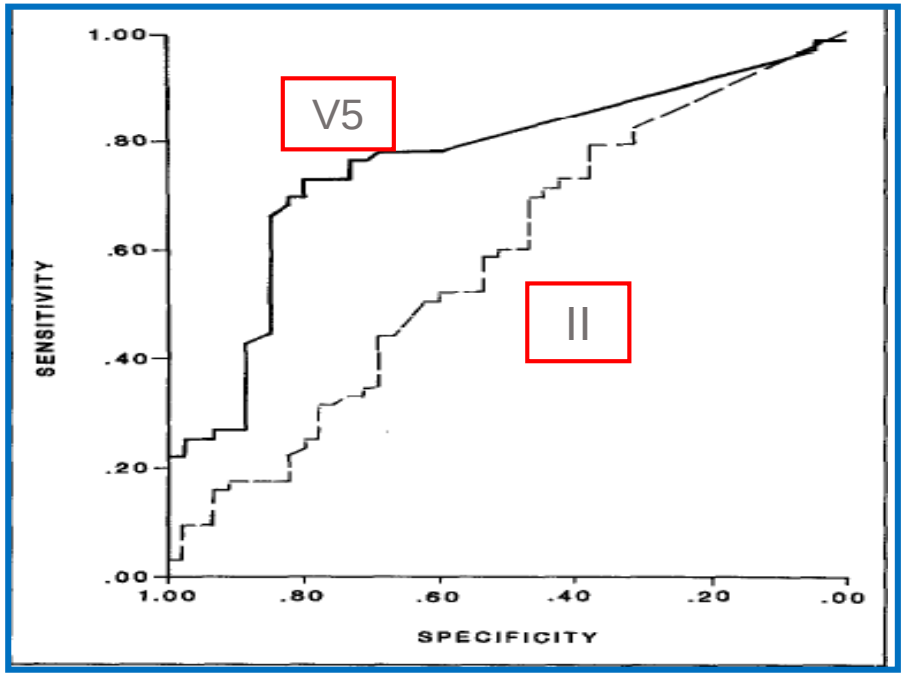
Which lead is the most helpful lead?

. Compare ST seg.depression in lead II c that in V5 as markers for CAD

. All (173 men) patients : had standard TMT & underwent diagnostic CAG

TABLE II Exercise Electrocardiogram Performance Using Leads II and V_5 for the Diagnosis of Any Coronary Artery Disease

	II	V_5
Sensitivity (%)	71	65
Specificity (%)	44	84
Positive predictive value/ post–test probability of any CAD (%)	64	85
Negative predictive value (%)	53	63



PPV & NPV in V5 is better than those of II

V5 : Single best lead for detection

V4, V5, V6 : most sensitive for subendocardial ischemia

Am J Cardiol 1992;69:303-307

Extent of ST Depression & Multiple leads

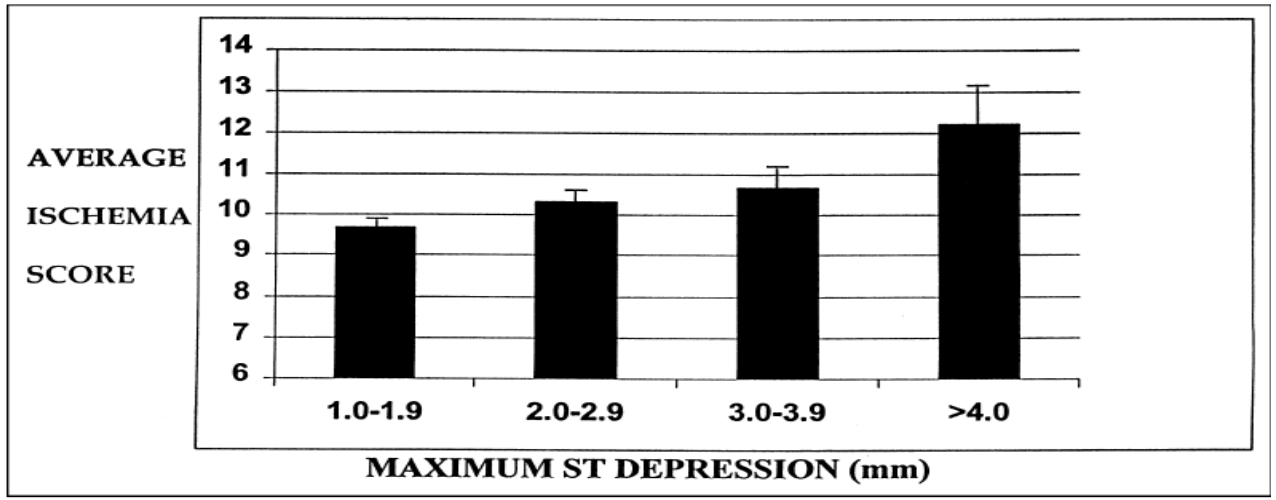


FIGURE 2. ST depression (in millimeters) related to extent of ischemia. Higher average ischemia scores are associated with greater average maximum ST depression. ($r = 0.04$, $p < 0.05$). Number of subjects in each category: 1 to 1.9, 108; 2 to 2.9, 65; 3 to 3.9, 17; >4, 5.

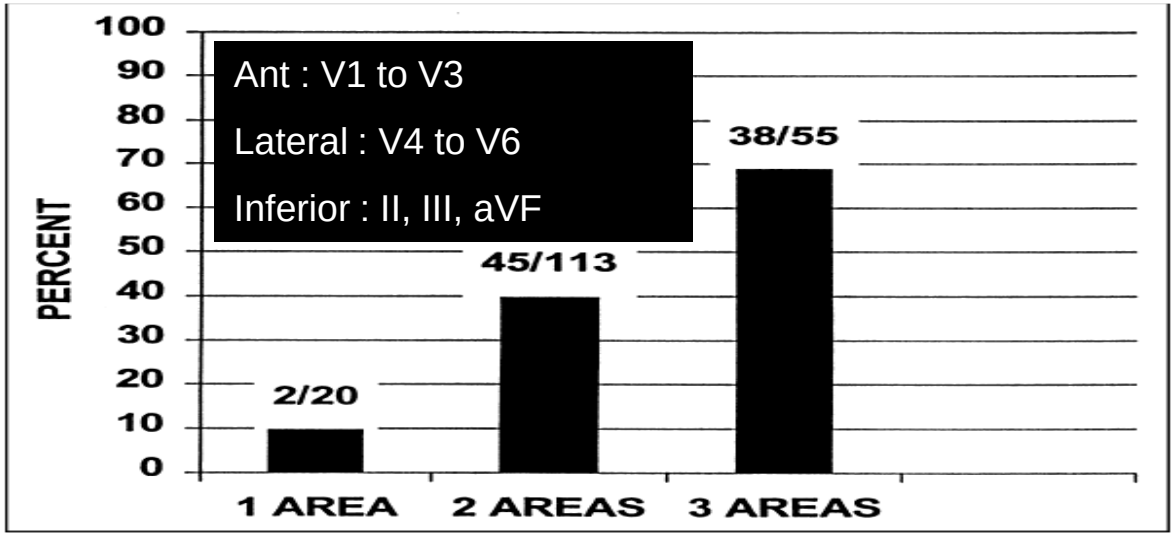


FIGURE 3. ST depression versus the number of ECG lead areas involved. Vertical axis displays percentage of individuals with ≥2 mm of stress-induced ST depression.

Greater ST depression involving multiple leads :

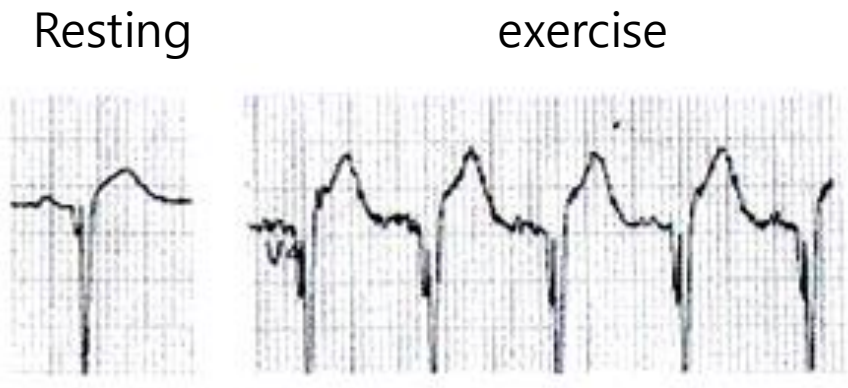
→ extensive myocardial ischemia

Am J Cardiol 1999;84:119-124

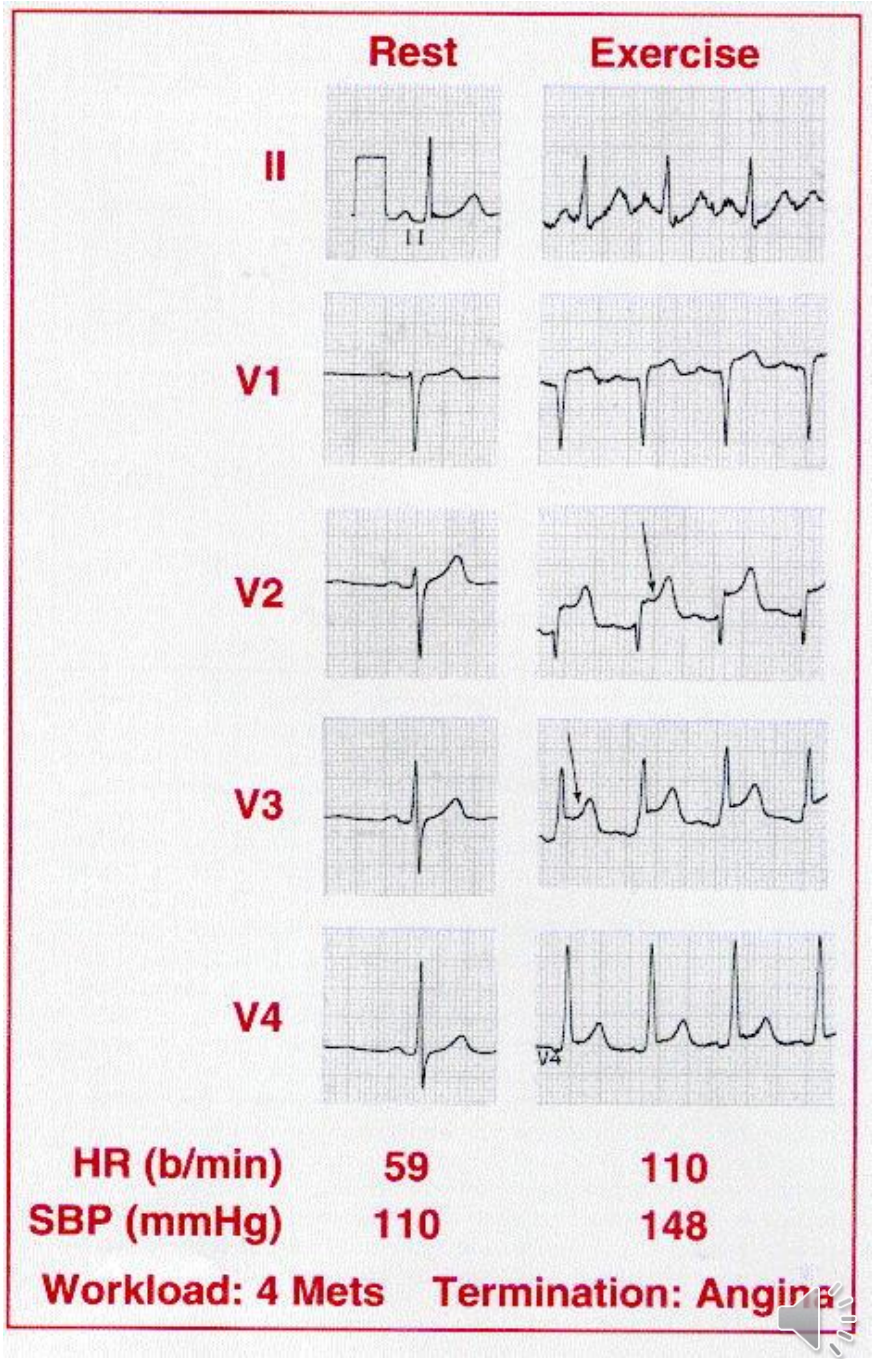
ST elevation

- ***ST-Segment Elevation in Postinfarction Patients With Q Waves.***

  - The development of >0.10 mV of J-point elevation at 60 ms after the J point is considered an abnormal response.
  - In the presence of prior Q-wave MI, this could represent reversible ischemia in the peri-infarct area or ventricular dyskinesis or akinetic LV segmental wall motion.
  - Myocardial imaging techniques can help distinguish the concomitant presence of a new myocardial ischemic zone from reciprocal changes induced by ST-segment elevation in Q-wave leads.



- ***ST-Segment Elevation in Subjects Without Prior Infarction.***
  - In subjects without previous infarction (absence of Q waves on the resting ECG), ST-segment elevation during exercise frequently localizes the site of severe transient combined endocardial and subepicardial ischemia resulting from significant subtotal proximal occlusive CAD.



Indications for Termination of Exercise Testing

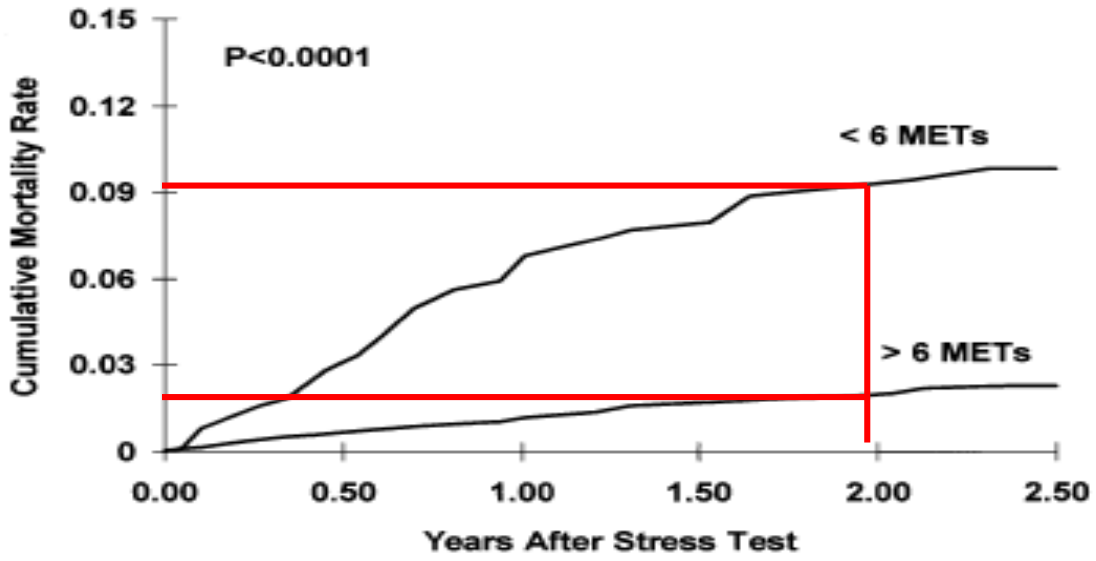
Absolute Indications

- ST-segment elevation (>1.0 mm) in leads without preexisting Q waves because of prior MI (other than aVR, aVL, and V1)
- Drop in systolic blood pressure >10 mm Hg, despite an increase in workload, when accompanied by any other evidence of ischemia
- Moderate-to-severe angina
- Central nervous system symptoms (eg, ataxia, dizziness, near syncope)
- Signs of poor perfusion (cyanosis or pallor)
- Sustained ventricular tachycardia (VT) or other arrhythmia, including second- or third-degree atrioventricular (AV) block, that interferes with normal maintenance of cardiac output during exercise
- Technical difficulties in monitoring the ECG or systolic blood pressure
- The subject's request to stop

Only ST change??

- **Functional capacity**
- **Duke treadmill score**
- **BP response**
- **Chronotropic incompetence**
- **HR recovery**

Prognosis – Functional capacity



. Functional capacity as a predictor of cardiovascular risk, for 2 yrs

. 3400 adults

J Am Coll Cardiol 1997;30:641-8

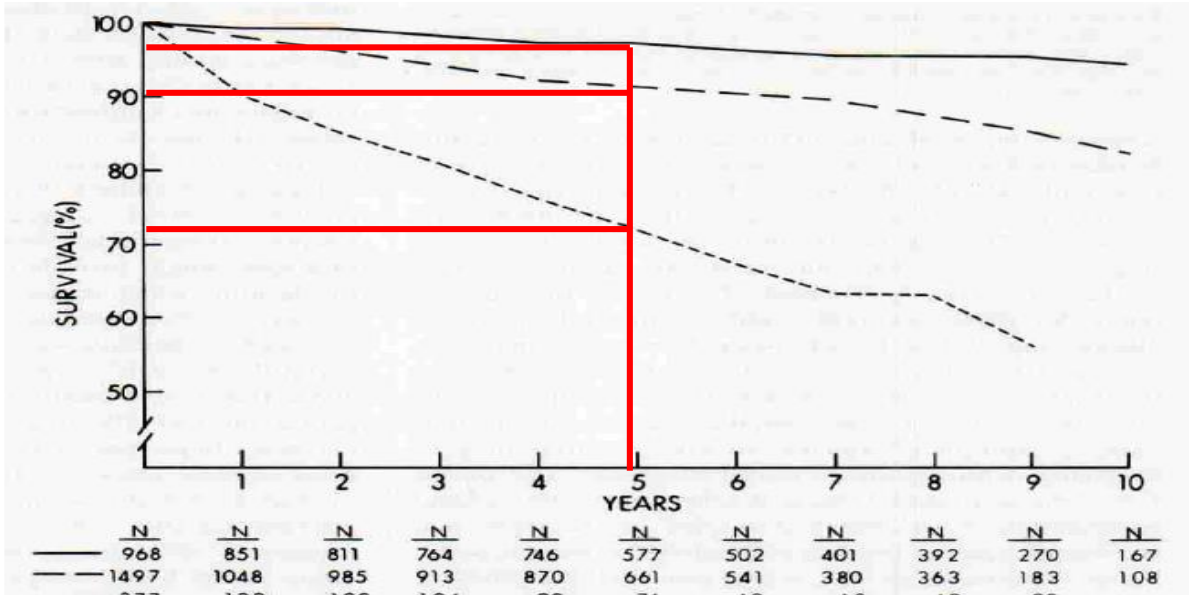
Duke TMT score

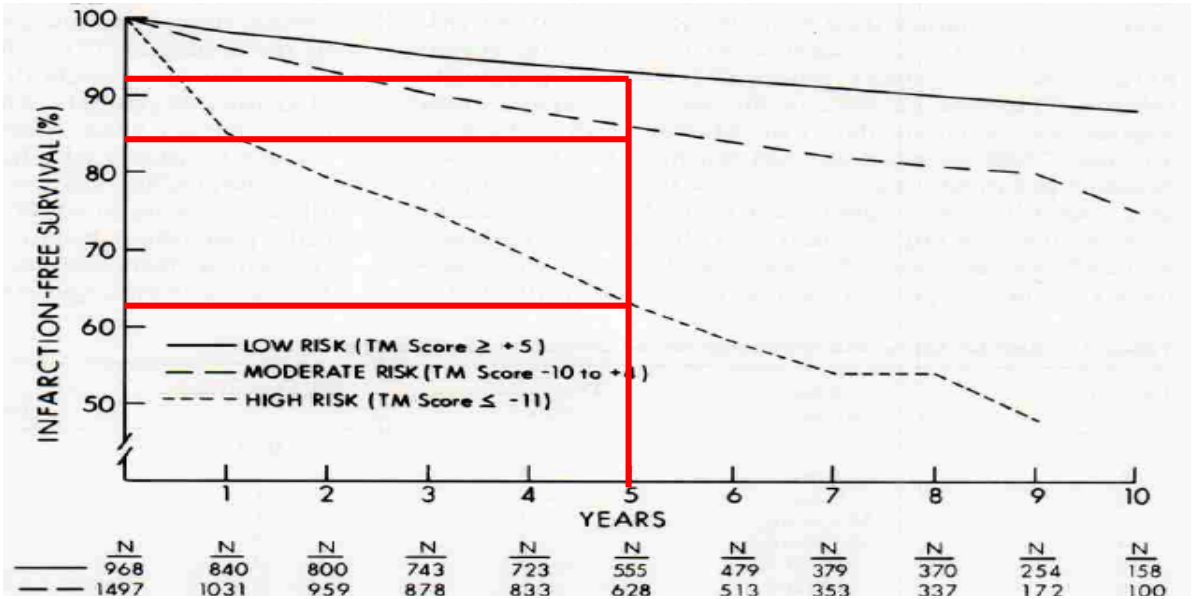
Duration of exercise(min) - { 5 x max.ST seg.deviation(mm) } – { 4 x angina index }

. Angina Index

0 : no angina, 1 : non-limiting angina, 2 : stop exercise due to angina

. Low risk : ≥+5, Moderate risk : -10 to +4, High risk : ≤ -11





	Rate	4 year survival	Annual mortality rate
Low risk (≥+5)	62%	99%	0.25%
Moderate risk	34%	95%	1.25%
High risk(≤-11)	4%	79%	5.0%

Annals of Internal Medicine. 1987;106:793-800

Abnormal hypotensive response during exercise

An inadequate rise in SBP (<20 to 30mmHg) or drop (>10~20 mmHg):

- **Aortic outflow obstruction**
- **Severe LV dysfunction**
- **Myocardial ischemia**
- **Certain type of drug therapy (β-blocker)**

. In most study, exercise induced hypotension :

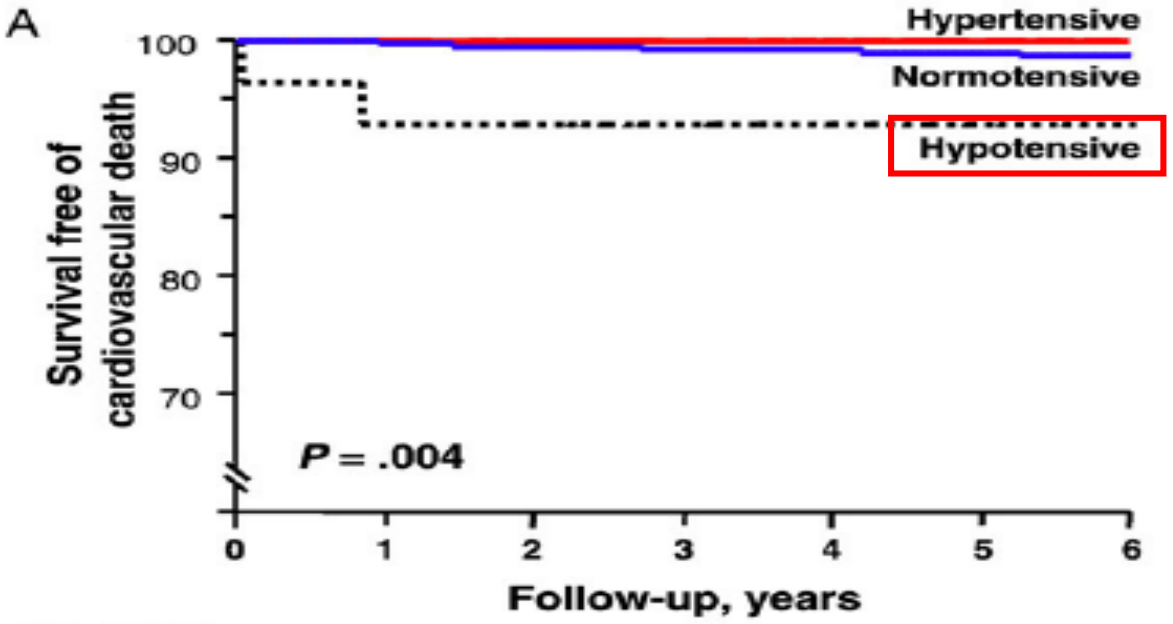
- **Predict a poor prognosis (LV dysfunction, myocardial ischemia)**
- **positive predictive value of 50% of Lt.main, 3 vessel Dz**
- **can occur in subjects with CAD, VHD, cardiomyopathy.**
- **during exercise related dehydration, prolonged strenuous exercise**
- **may influenced by anti-HTN medication**

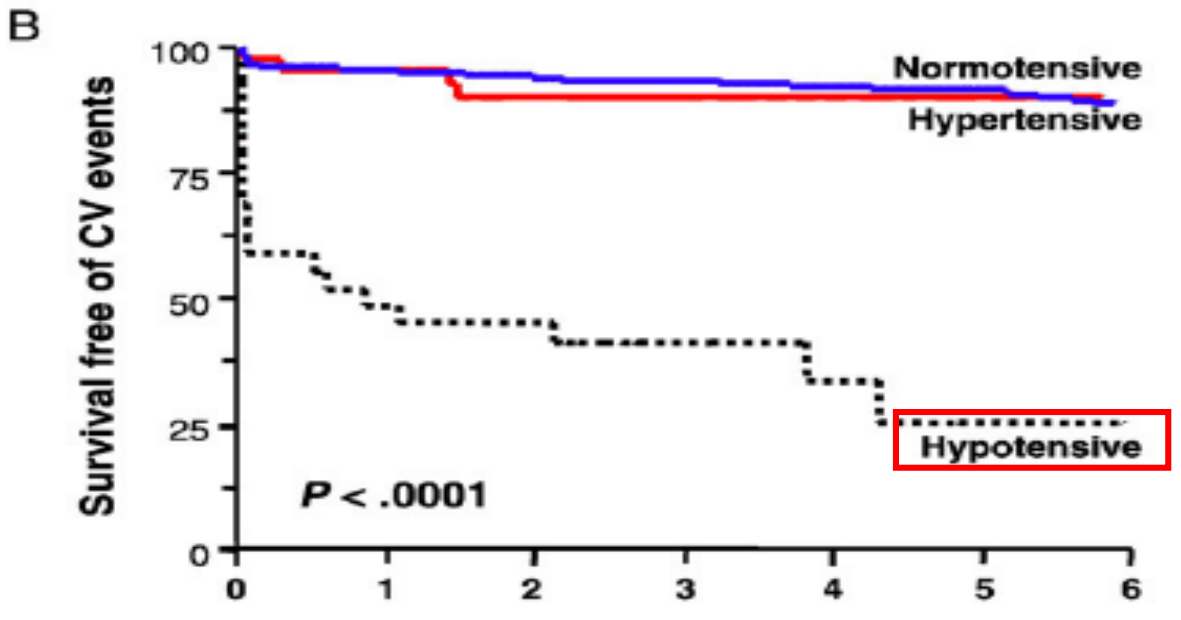
Circulation. 2001;104:1694-1740

. Hypotensive response :

.a fall in BP with exercise is an established poor prognostic marker

.decreased exercise capacity, abnormal perfusion image, CV mortality





Am Heart J 2008;155:930-7

Abnormal Hypertensive response

. Ideal cutoff for peak SBP seems to vary among different investigator

. Most would agree that a value ≥ 220 mmHg requires closer F/U

Am J Cardiol 2007;100:1609-1613

. Abnormal hypertensive response :

.SBP > 200~225 mmHg, DBP > 10~15 mmHg from baseline DBP

.Predictor of future HTN in normotensives

.Higher false positive ST response in chronic HTN with LVH

Circulation. 2001;104:1694-1740

Heart Rate recovery (HRR)

. Value of HRR :

.difference between HR peak exercise & 1 minute later

.Abnormal HRR was defined as :

≤12 beats/min for TMT

≤18 beats/min for stress echocardiography

N Engl J Med 1999;341:1351-1357
JAMA.2000;284(11):1392-1398
J Am Coll Cardiol 2003;42:831-8

Heart Rate Recovery After Exercise Is a Predictor of Mortality, Independent of the Angiographic Severity of Coronary Disease

. To examine association between abnormal HRR & mortality

. 2395 patients, TMT & CAG within 90 days, 6 years F/U

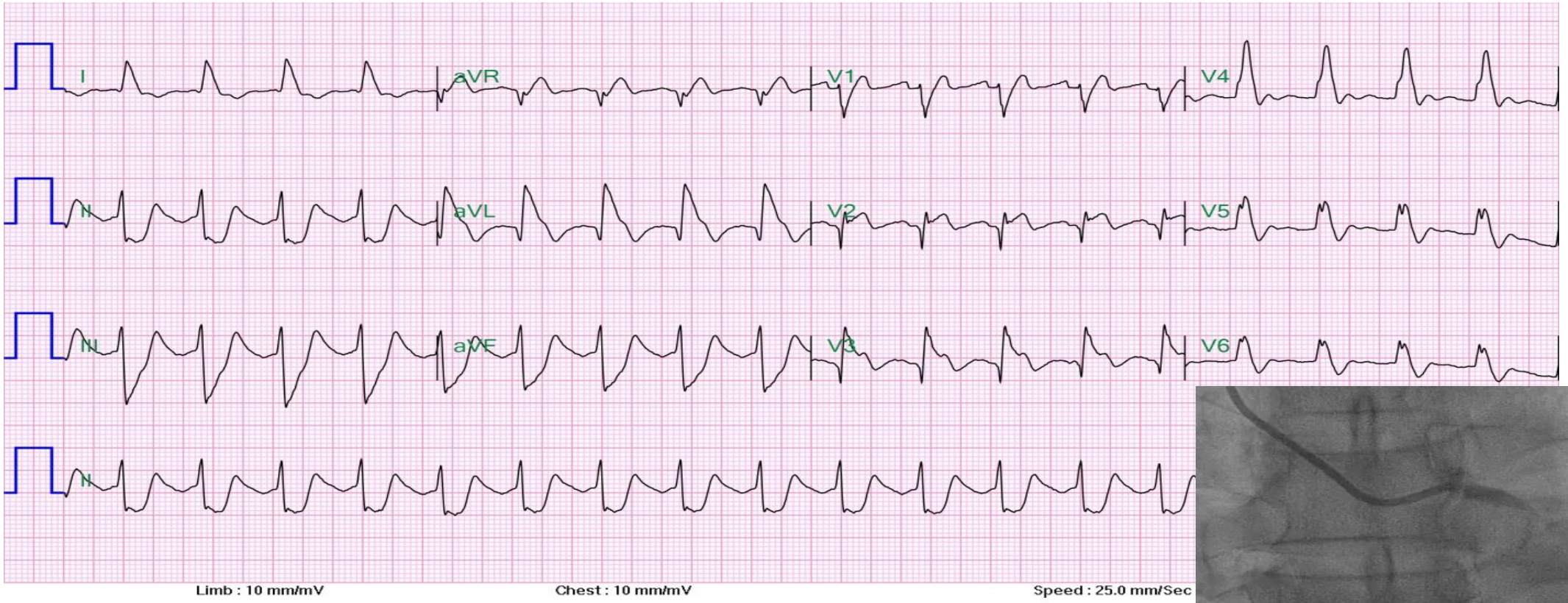
. Primary end point : all cause mortality

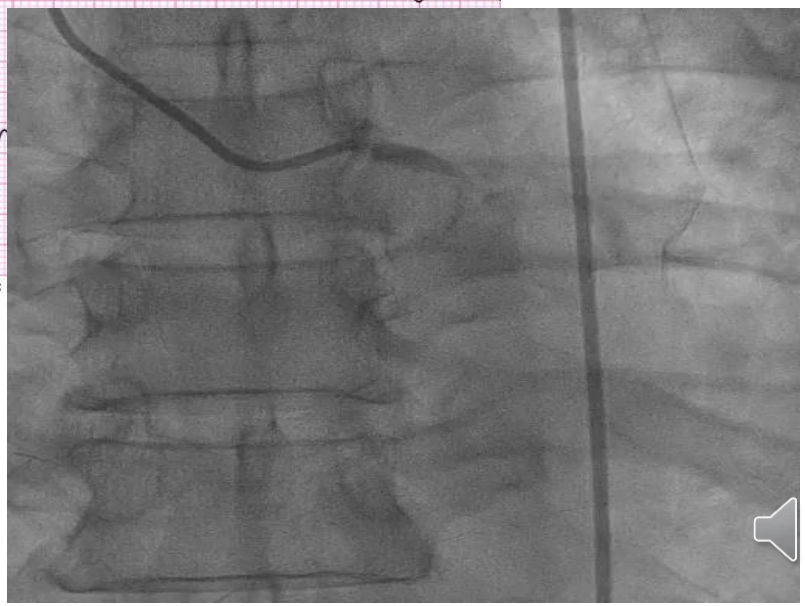
Table 3. Angiographic and Ventriculographic Characteristics According to HRR

Characteristic	Normal HRR (n = 2,097)	Abnormal HRR (n = 838)	p Value
Duke CAD index	19 (0–32)	23 (0–37)	< 0.0001
Any CAD	1,279 (61%)	576 (69%)	< 0.0001
Severe CAD (prognostic score ≥42)	280 (13%)	141 (17%)	0.02
LMCA disease	79 (4%)	41 (5%)	0.16
Proximal LAD disease	476 (23%)	230 (27%)	0.007
LCx disease	593 (29%)	282 (34%)	0.004
RCA/PDA disease	757 (36%)	368 (43%)	< 0.0001
Low ejection fraction (≤40%)	537 (25%)	269 (32%)	0.0004

J Am Coll Cardiol 2003;42:831-8

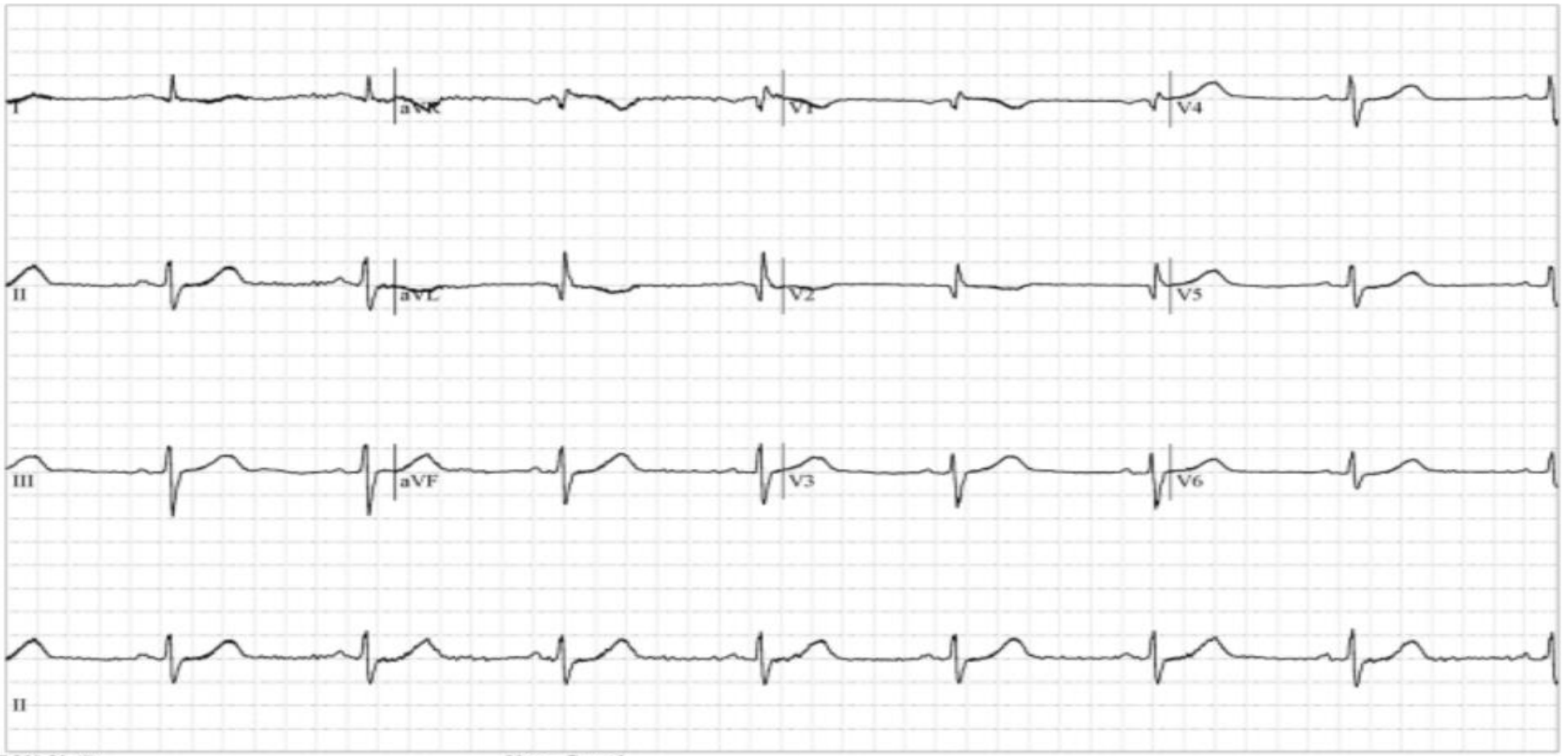
M/65, Chest pain, ER



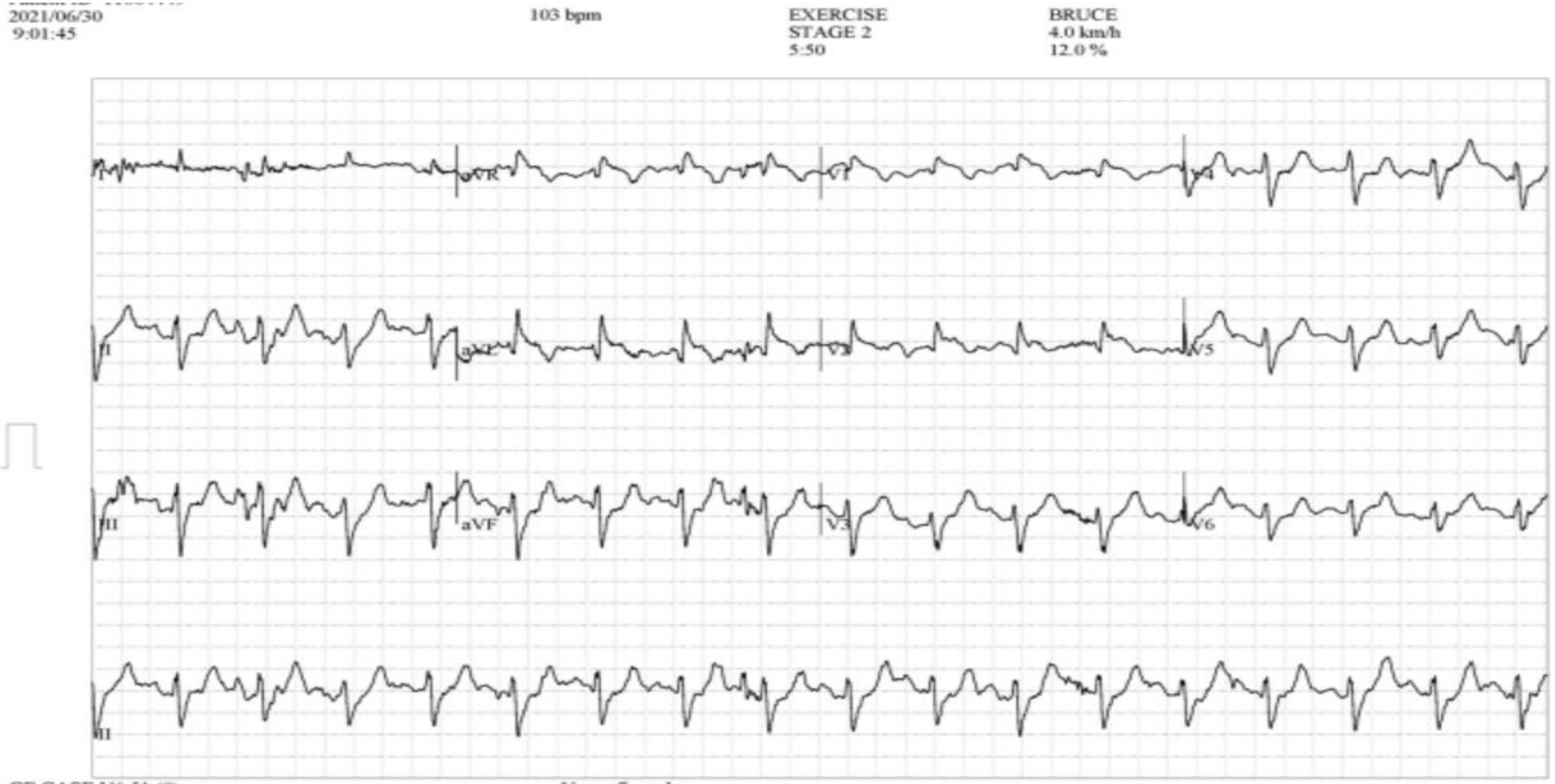


1 yr after PCI, No Sx. EF 40%
Fu CAG with TMT

Pretest, standing, 121/74 mmHg, 52 bpm



Stage 2 (7 METS), 93/61 mmHg, 103 bpm,
SBP drop 28mmHg during exercise: abnormal hypotensive response
ST elevation > 1 mm (previous Q wave) chest pain(-), stop exercise d/t dyspnea



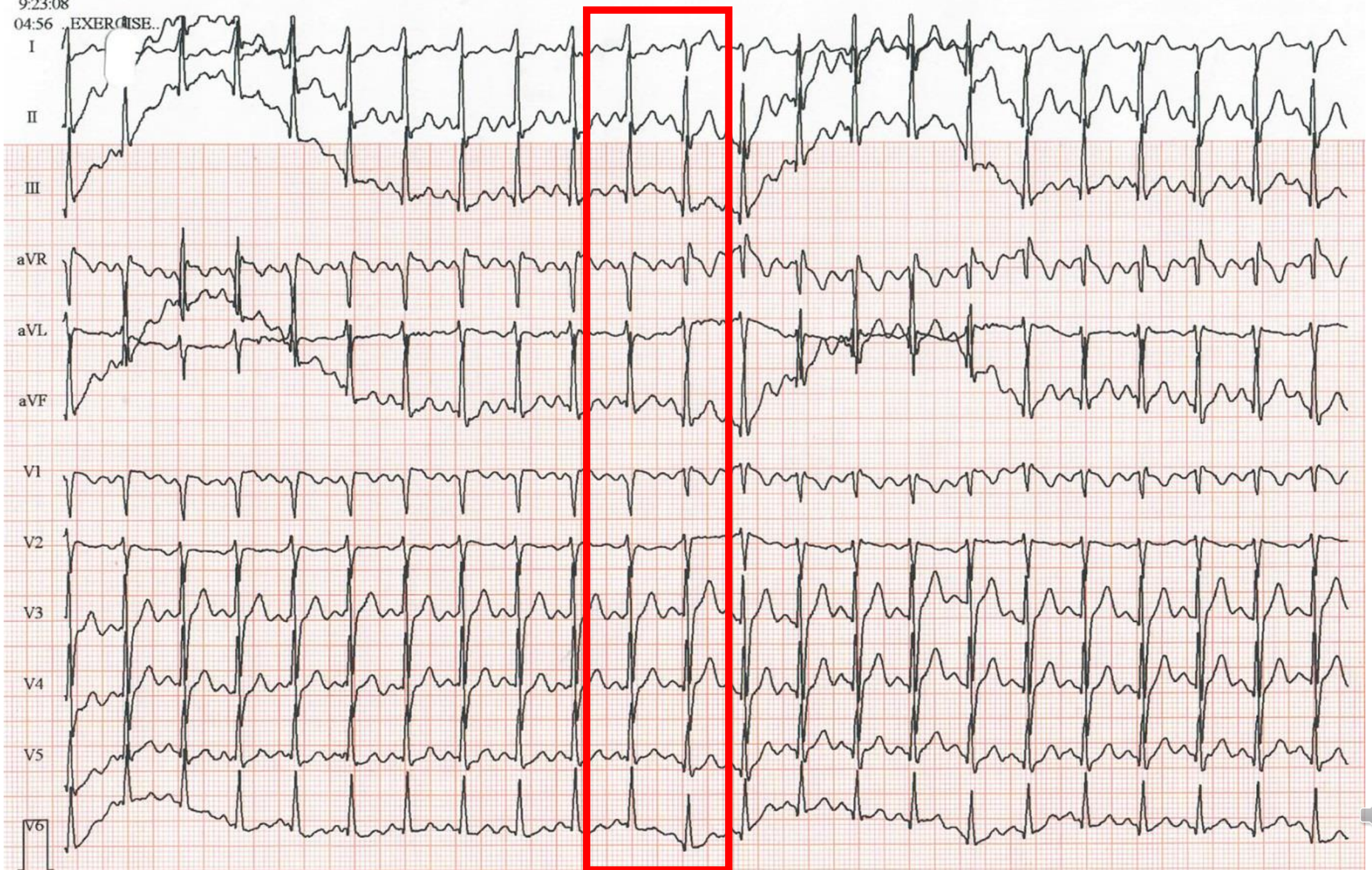
Recovery 1 min, 96 bpm.

Peak HR – Recovery 1 min HR = 7 (abnormal heart rate recovery)
Duke's score : -4 (moderate risk)

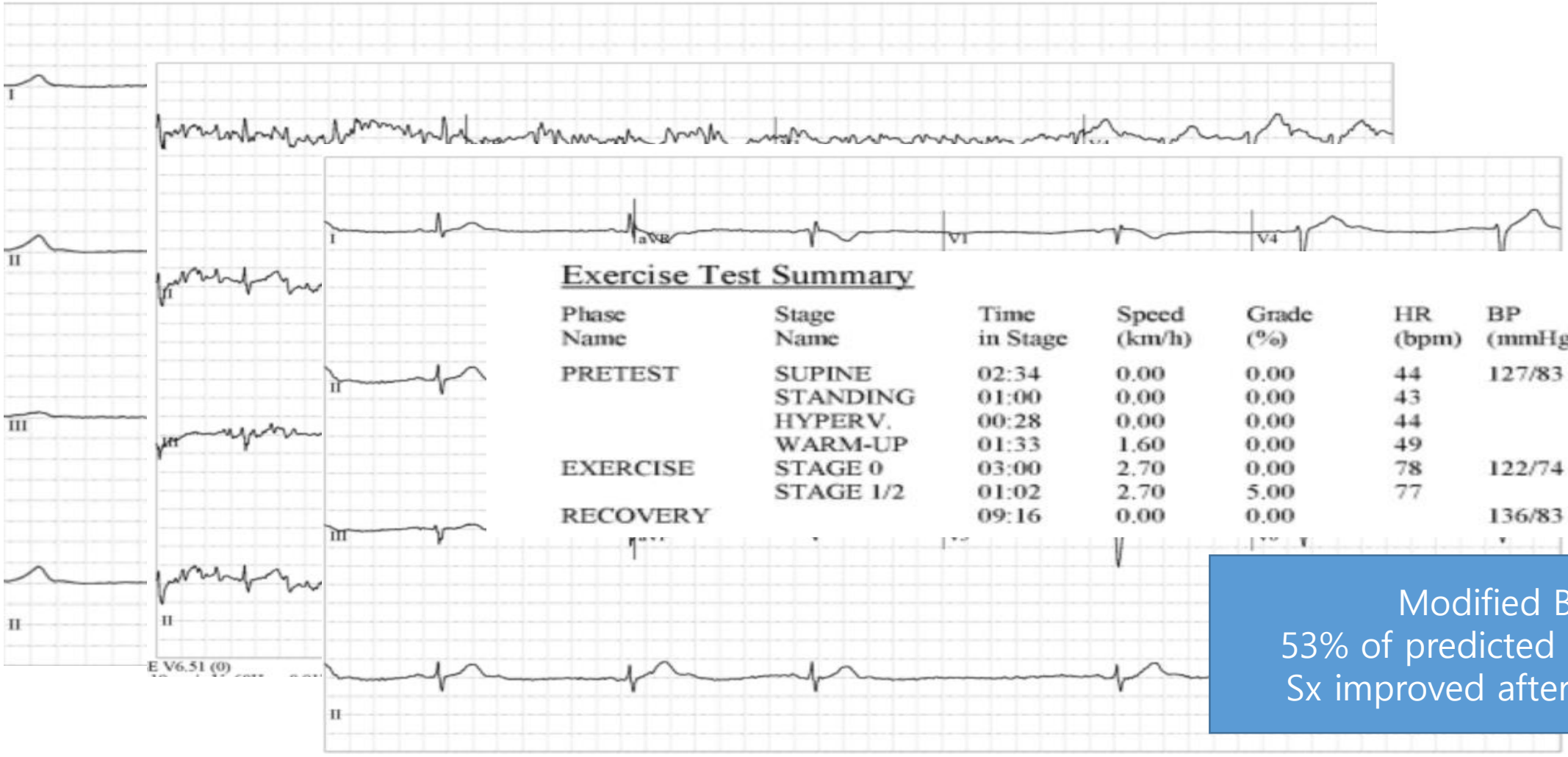
CAG: No ISR. Continue medical Tx for ischemic HF

M/29 No Sx.
WPW

Disappearance of delta wave during exercise
Intermittent delta? Or d/t shortened PR interval during exercise?


9:23:08
04:56 EXERCISE
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6

M/74, dizziness, syncope, DOE
Holter: PAF, sinus bradycardia, intermittent 3.5 sec pause.
Normal EF, lung. PCI Hx → no ISR



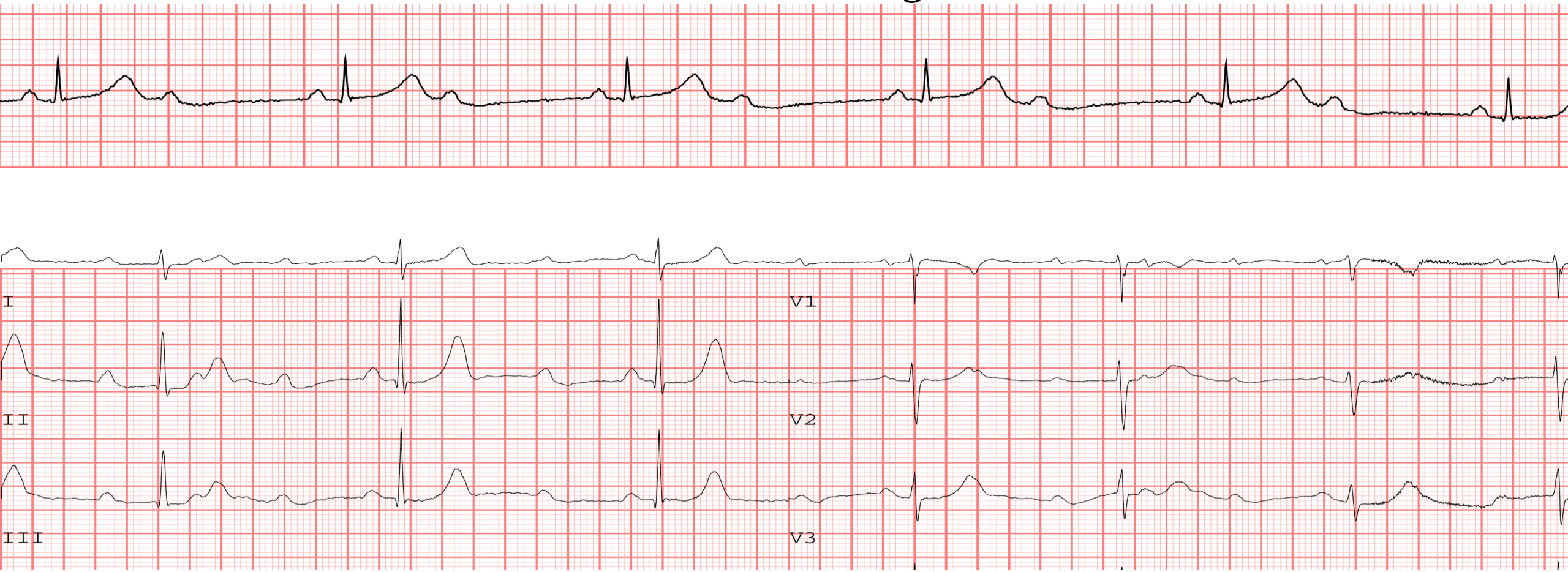
Exercise Test Summary

Phase Name	Stage Name	Time in Stage	Speed (km/h)	Grade (%)	HR (bpm)	BP (mmHg)
PRETEST	SUPINE	02:34	0.00	0.00	44	127/83
	STANDING	01:00	0.00	0.00	43	
	HYPERV.	00:28	0.00	0.00	44	
	WARM-UP	01:33	1.60	0.00	49	
EXERCISE	STAGE 0	03:00	2.70	0.00	78	122/74
	STAGE 1/2	01:02	2.70	5.00	77	
RECOVERY		09:16	0.00	0.00		136/83

Modified Bruce
53% of predicted maximal HR
Sx improved after Pacemaker

2:1 AV block

Resting



Treadmill test: aggravation of AVB (3 to 1 conduction), suggests infra-nodal block

Summary

- TMT indication
  - TMT is a good method to detect inducible cardiac ischemia in symptomatic intermediate-risk patients who can exercise and who have interpretable ECG
  - Important tool for certain arrhythmias (exercise induced arrhythmia, symptomatic chronotropic incompetence, WPW, etc)
- Interpretation
  - Consider baseline ECG and normal change during exercise
  - Patient selection is important to increase sensitivity/specificity
  - Positive: horizontal or downsloping ST depression≥0.1mV at 60-80ms after J point, in 3 consecutive beats
  - Equivocal: upsloping ST depression
  - Additional information about prognosis (exercise capacity, HR, BP response)

Thank you for attention