Internet Symposium 2008

SIMPLE HEART RATE ADJUSTMENT OF ST SEGMENT DEPRESSION DURING EXERCISE TESTING

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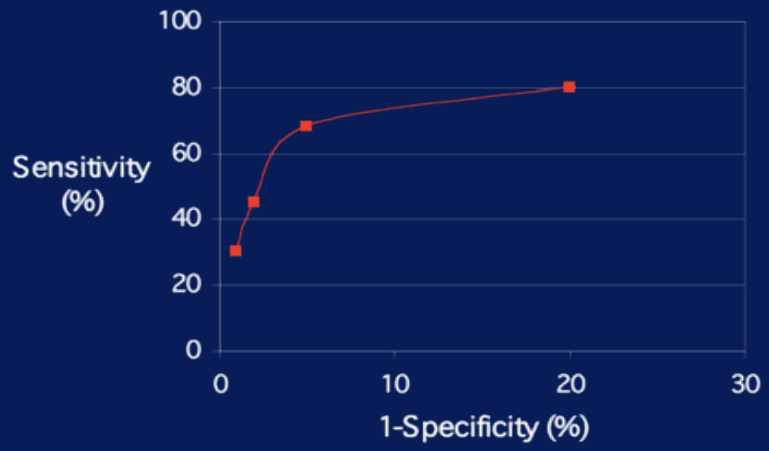
RETHINKING THE EXERCISE ECG



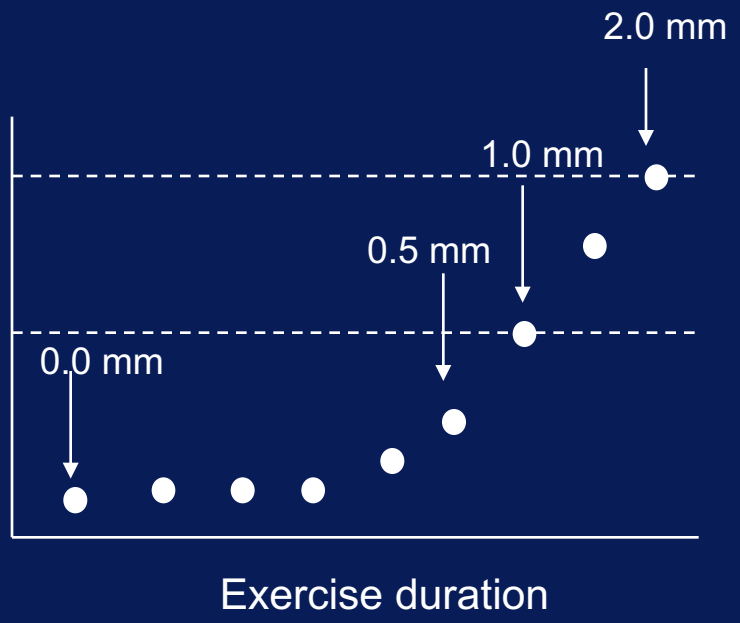
In sum:
Poor sensitivity of the standard exercise ECG for ischemia is the major diagnostic weakness and the critical limitation of the test

Why is this?

RETHINKING THE EXERCISE ECG: DETECTION OF ISCHEMIA

The standard exercise test is defined by a *threshold ST segment depression partition*:

½ mm STD = negative test
1 mm STD = positive test
2 mm STD = very positive test



So...., what's the problem?

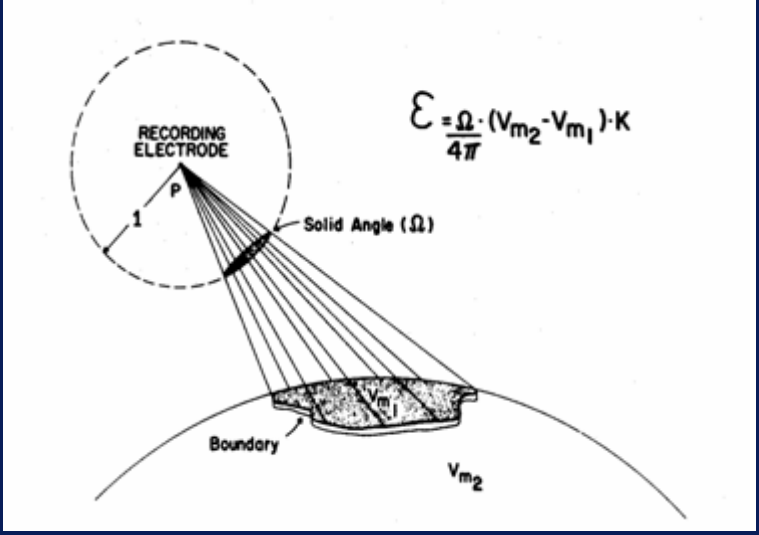
WHAT'S WRONG WITH THE EXERCISE ECG?

ST segment depression is the problem:

ST depression at peak exercise does not work very well for the identification of coronary artery disease or for the assessment of its anatomic severity, and it is not a strong marker for the presence of vulnerable plaque that leads to acute coronary syndromes

We need to go beyond the ST segment

SOLID ANGLE THEORY: SPATIAL AND NONSPATIAL DETERMINANTS OF VOLTAGE



From Holland and Arnsdorf

ST segment depression is directly related to both:

- A *spatial* factor: the solid angle subtended by the induced ischemic boundary (*anatomic area of ischemia*)
- A *non-spatial* factor: the voltage drop across the ischemic boundary (*metabolic severity of ischemia*)

SPATIAL AND NONSPATIAL DETERMINANTS OF VOLTAGE

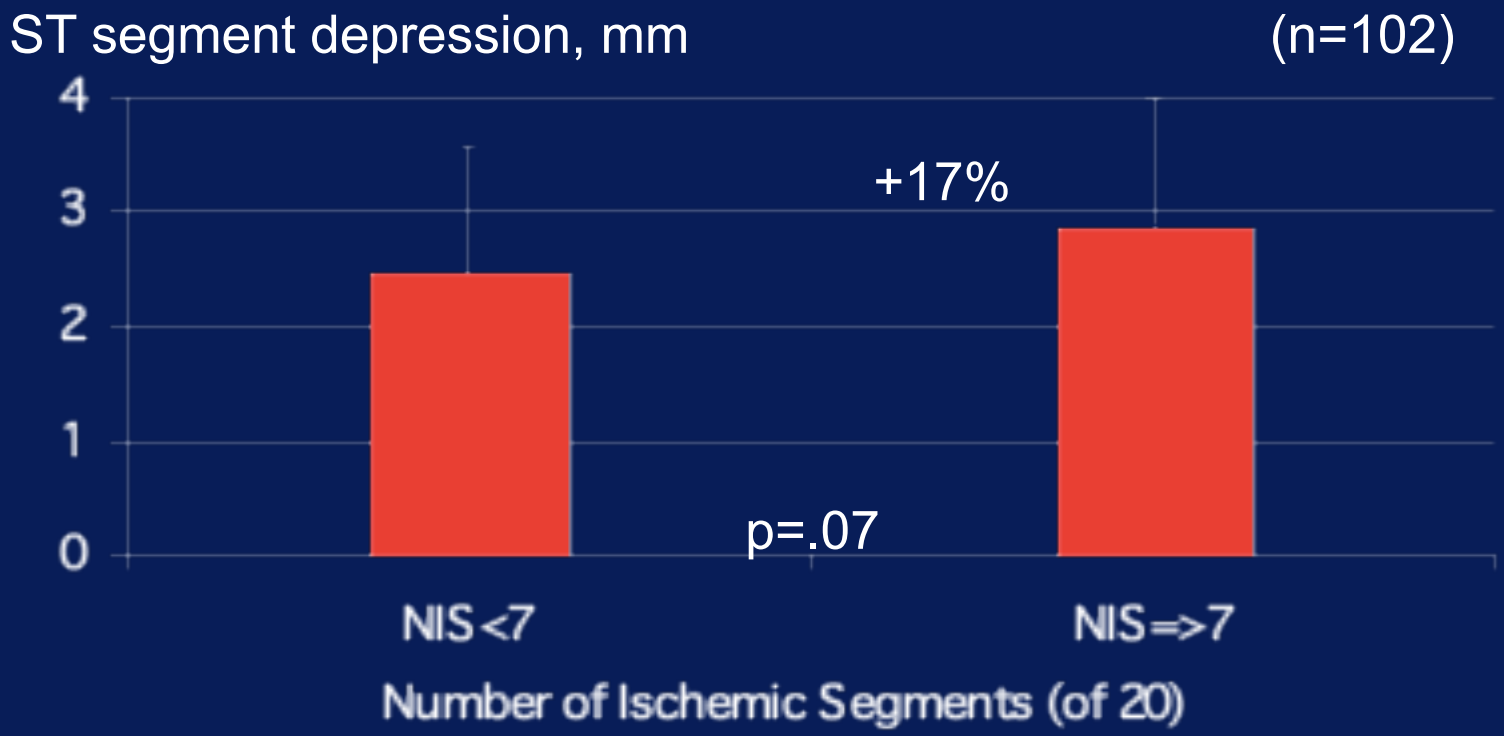
ST segment depression
is directly related to both:

The *anatomic extent* of ischemia

The *functional severity* of ischemia

SPATIAL FACTORS AND STD

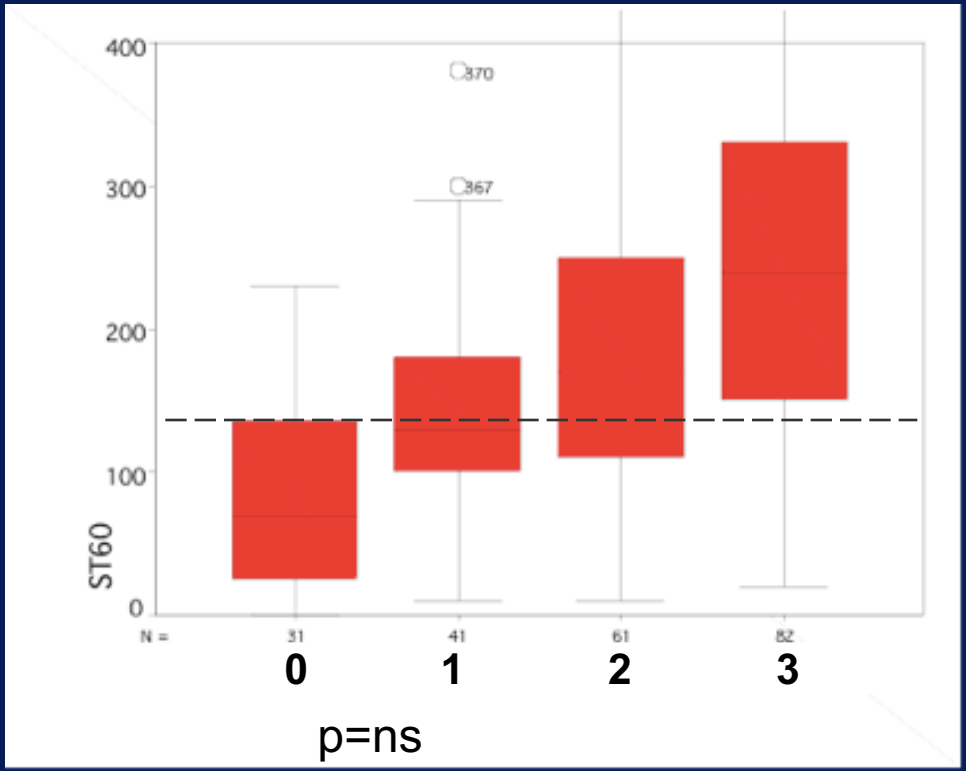
Relation of ST depression to *number* of SPECT ischemic segments during exercise



Am J Card 2005; 96:1356

STD IN RELATION TO THE PRESENCE AND EXTENT OF CAD

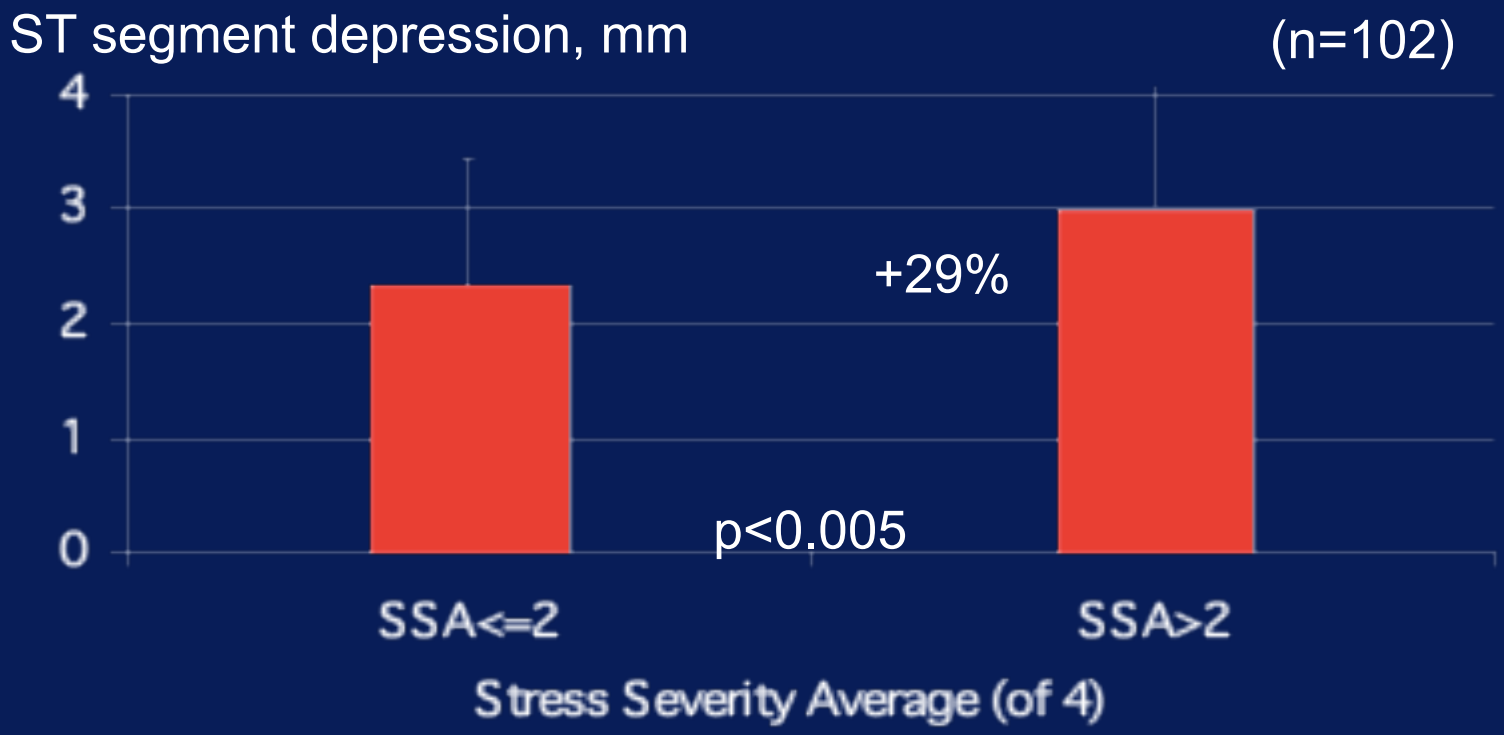
ST depression (uV)



Extent of CAD (number of obstructed arteries)

NON-SPATIAL FACTORS AND STD

Relation of ST depression to average stress severity score in SPECT ischemic segments

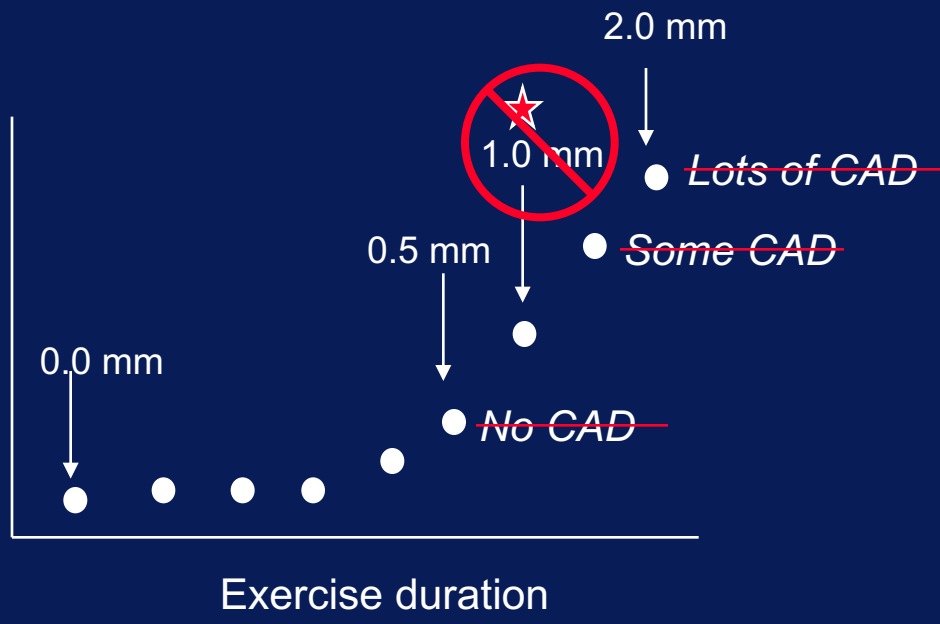


Am J Card 2005; 96:1356

PHYSIOLOGIC LIMITATION OF THE STANDARD EXERCISE TEST CRITERION

Because STD is driven by *variable exercise load*,

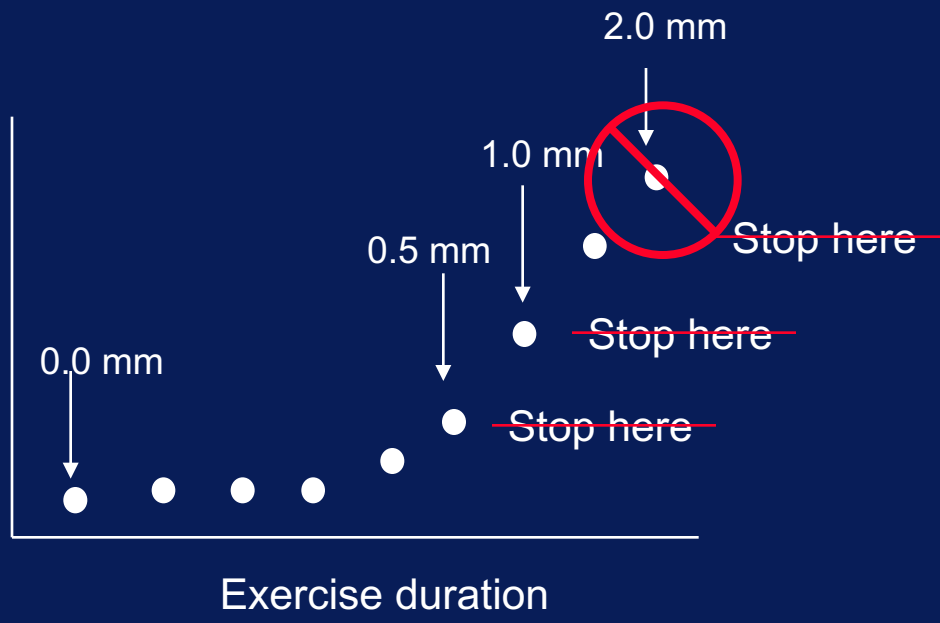
- *1 mm of STD* is an empiric partition, not a physiologically stable marker for identification of coronary artery disease



and....

PHYSIOLOGIC LIMITATION OF THE STANDARD EXERCISE TEST CRITERION

- *Peak exercise STD* is the *wrong* variable for evaluating the presence and extent of CAD, because it is workload dependent



To derive more useful information about ischemia, STD must be adjusted for dynamic factors that cause it to change during the course of exercise

ST DEPRESSION AND EXTENT OF MYOCARDIAL ISCHEMIA

From exercise physiology and the solid angle relationship:

ST segment depression during exercise-induced ischemia is directly related to both the *extent of coronary disease* and the *severity of ischemia induced by a changing myocardial workload*:

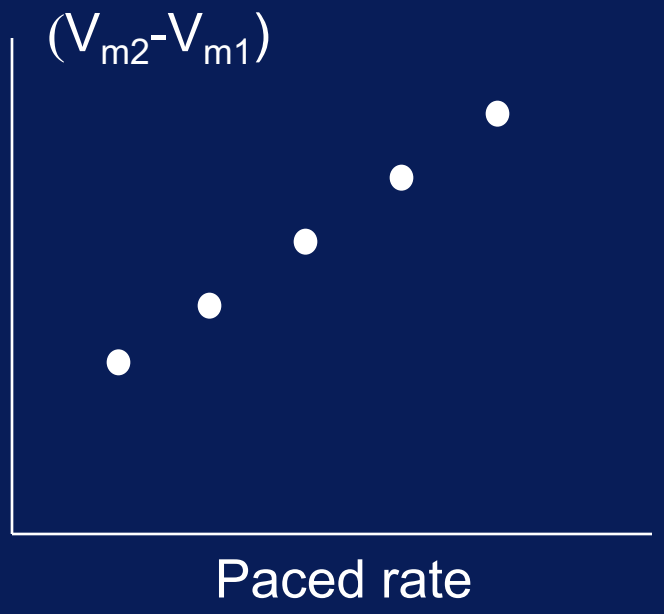
Apparent ischemia = Extent of disease x Severity of ischemia
(ST depression) (CAD) (Cardiac work)

Ω ΔV

HEART RATE AND NON-SPATIAL ISCHEMIC SEVERITY

Voltage across the ischemic boundary in isolated perfused myocardium is linearly related to driving (heart) rate

$$\Delta V = c \bullet \Delta HR$$



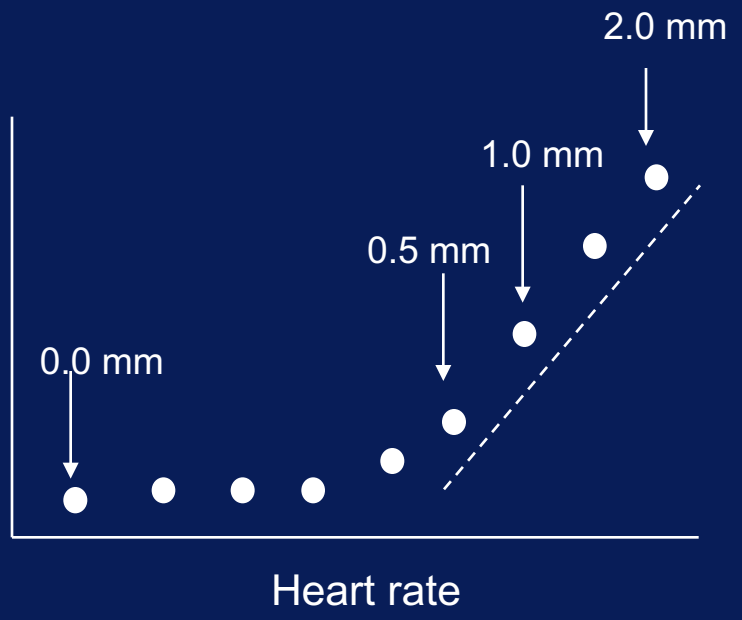
After Mirvis et al,
Circ Res 1978;42:676

PHYSIOLOGIC LIMITATION OF THE STANDARD EXERCISE TEST CRITERION

- *Time* (exercise duration) is the *wrong* variable for dynamic evaluation of ST segment depression
- *Heart rate* is a more relevant physiologic parameter for the analysis of ischemia (heart rate is linearly related to MVO_2)

HEART RATE ADJUSTMENT OF ST SEGMENT DEPRESSION

ST depression can be *adjusted* for the varying severity of ischemia (as HR) during higher levels of exercise *to clarify the extent of disease*:

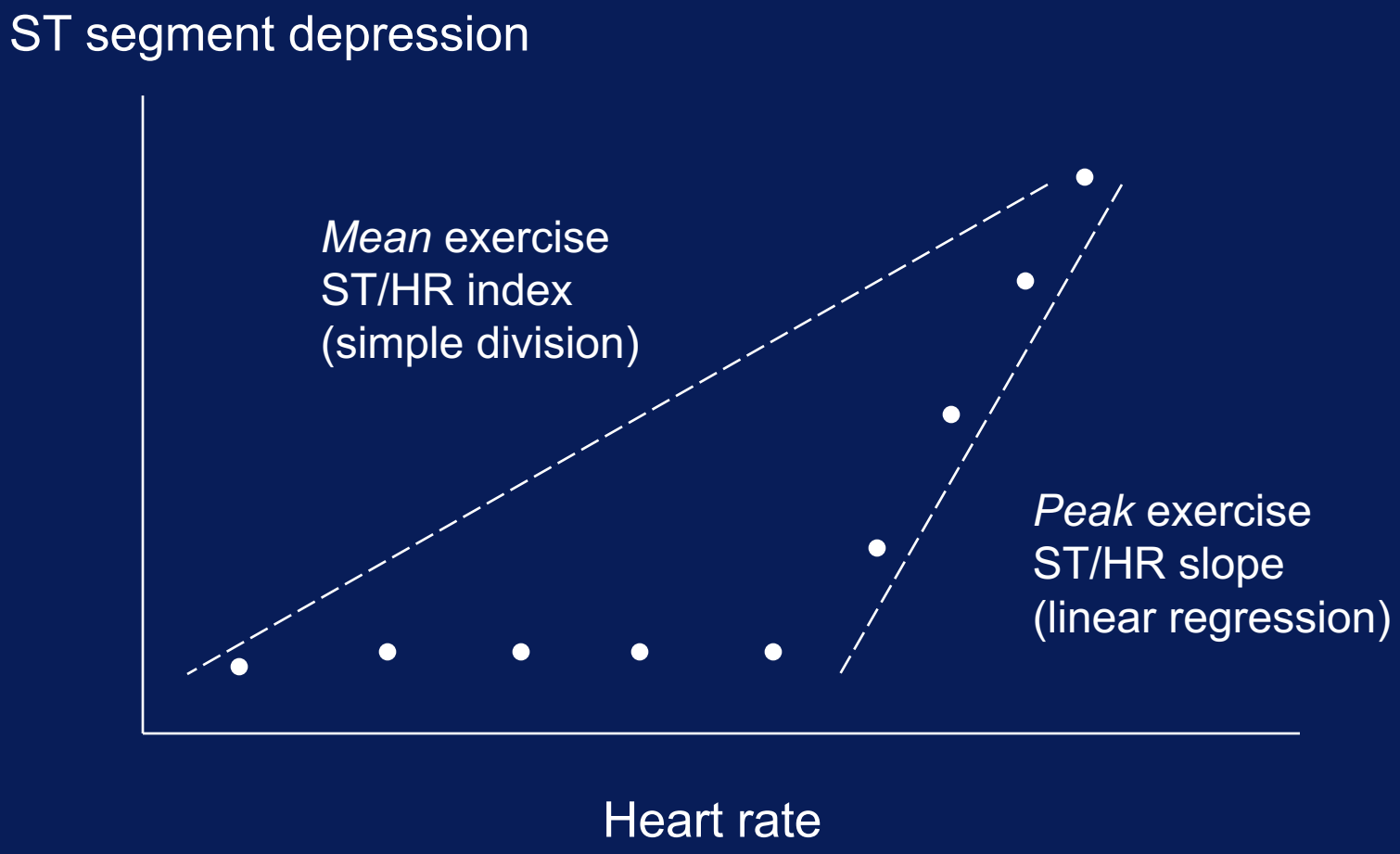


Apparent ischemia = Extent of disease x Severity of ischemia
(ST depression) (CAD) (HR)

So:

$$\text{Extent of disease} = \frac{\Delta \text{ ST depression}}{\Delta \text{ Heart rate}}$$

THE ST/HR SLOPE AND THE ST/HR INDEX



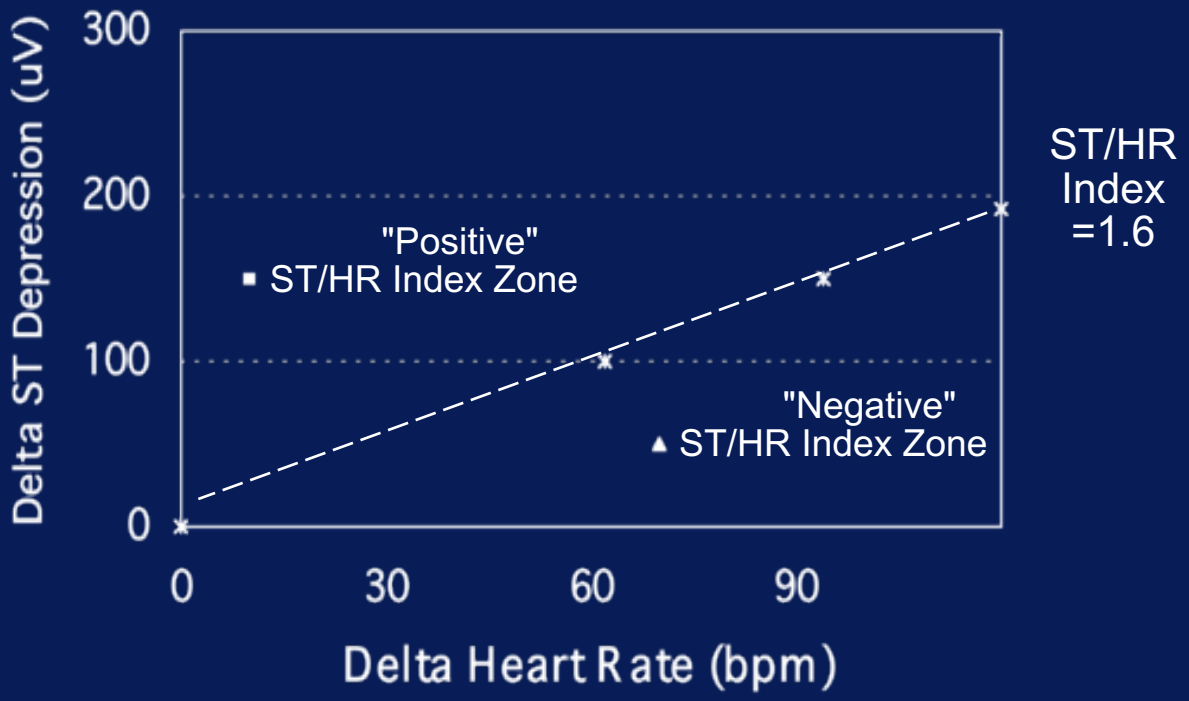
THE ST/HR INDEX: DERIVATION OF NORMAL VALUE AND USE AS CRITERION FOR CAD

- By percentile estimation, 95% of normal subjects found to have ST/HR Index < 1.6 uV/bpm (where 100 uV = 1.0 mm)

And therefore:

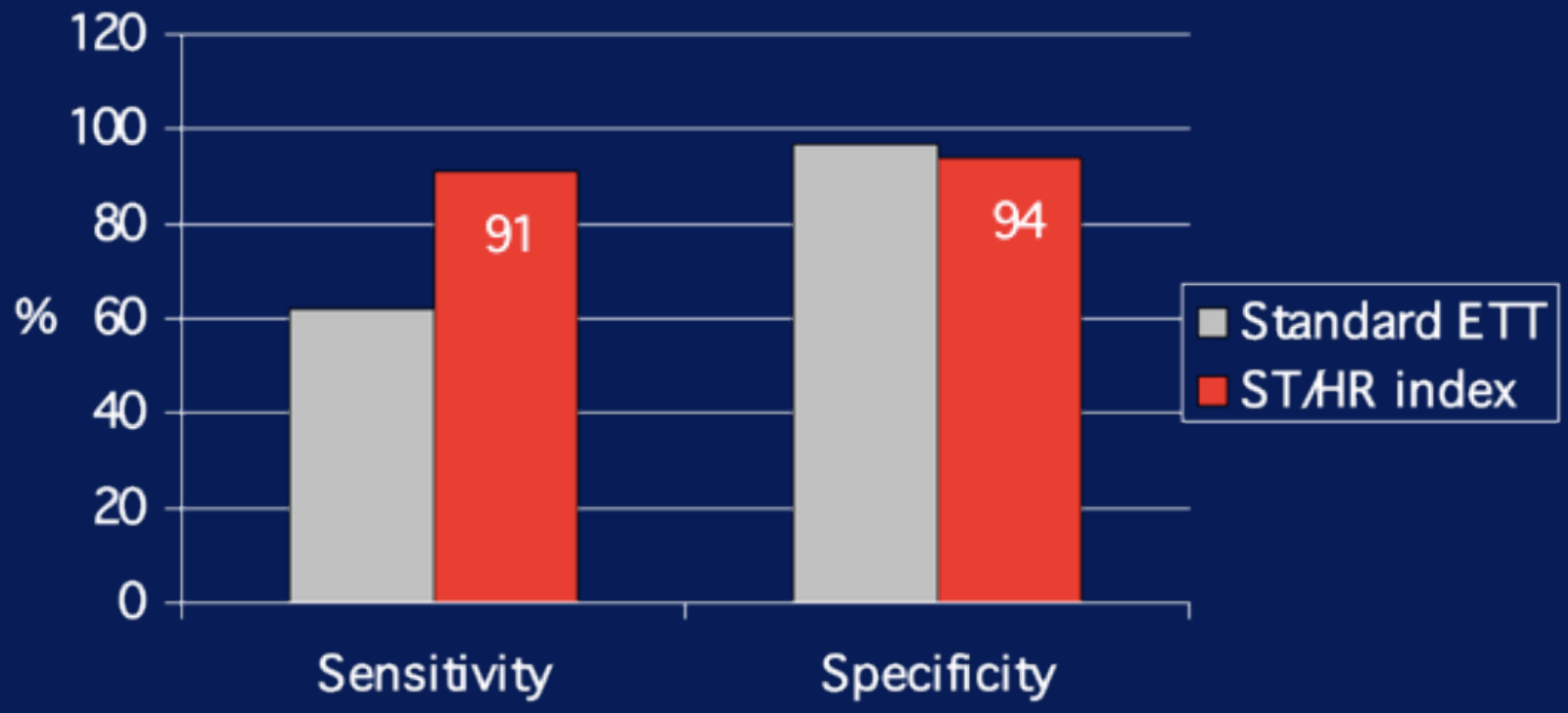
- ST/HR Index > 1.6 uV/bpm can serve as criterion for CAD:

Applied as test criterion:



HEART RATE ADJUSTMENT OF THE EXERCISE ELECTROCARDIOGRAM

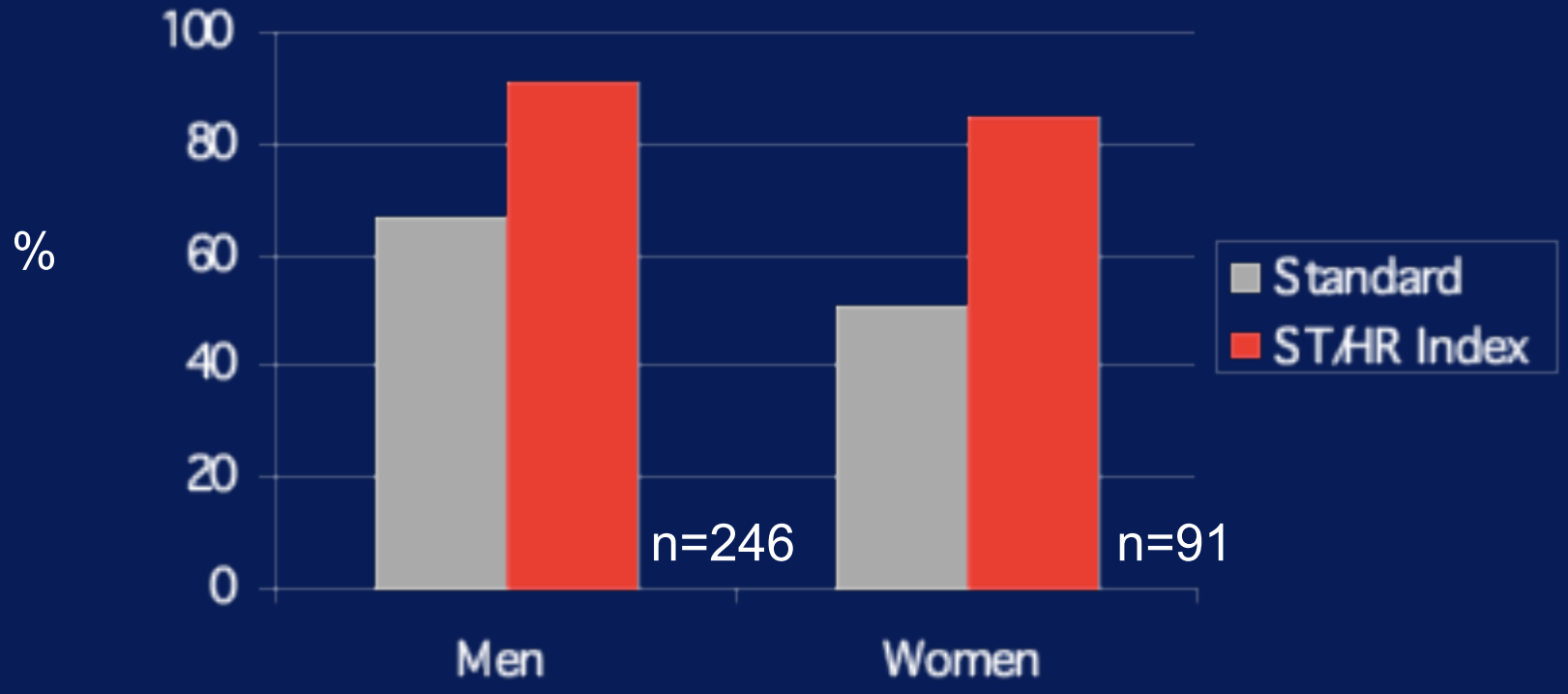
At high specificity, the ST/HR index improves the sensitivity of the exercise ECG for detection of CAD:



(n=549)

IDENTIFICATION OF CAD BY ST/HR INDEX CRITERIA IN MEN AND WOMEN

Sensitivity of ST/HR index and standard criteria at matched specificity (96%):



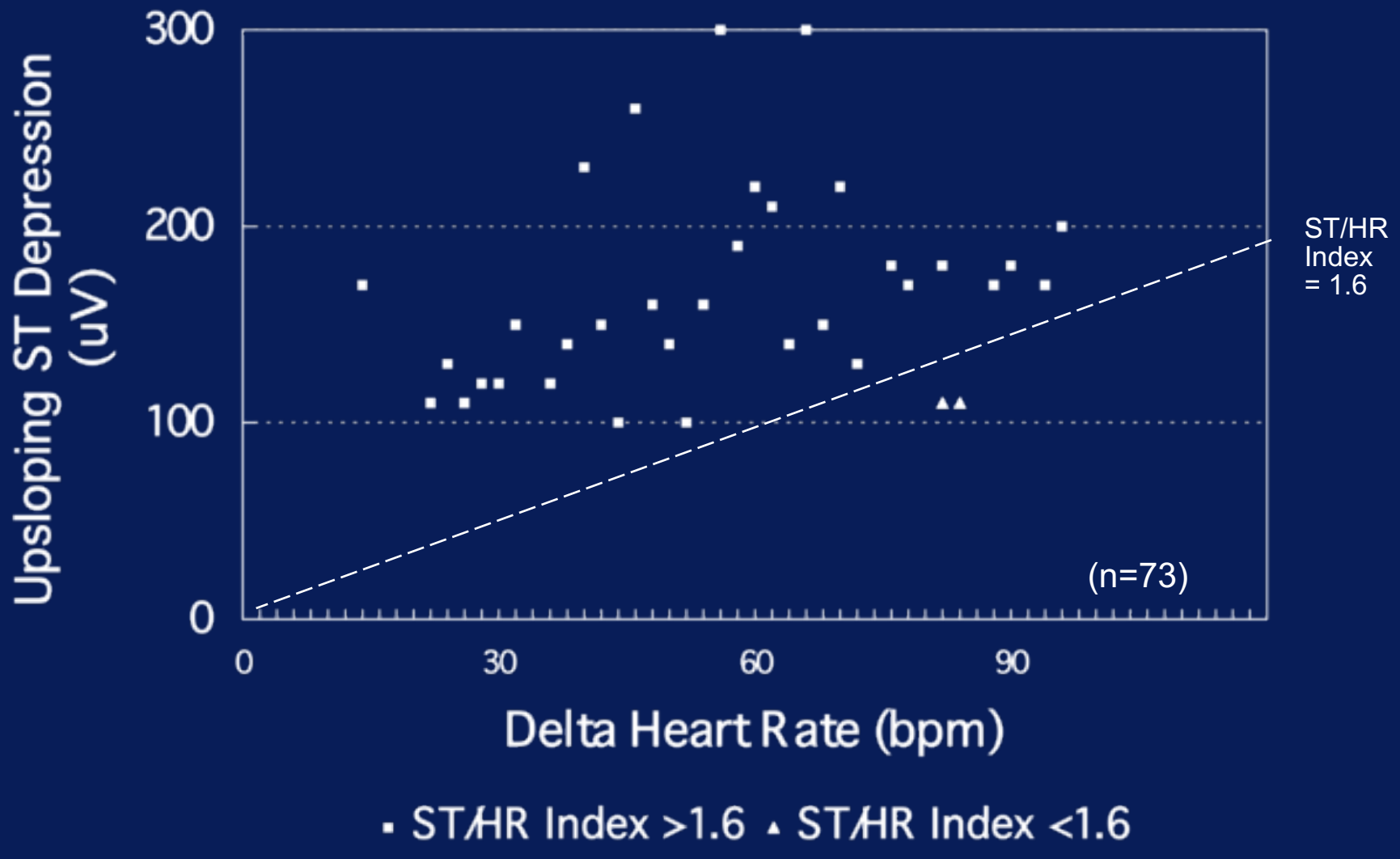
Circulation 1995;92:1209

IMPROVED SENSITIVITY OF THE ST/HR INDEX vs STANDARD TEST

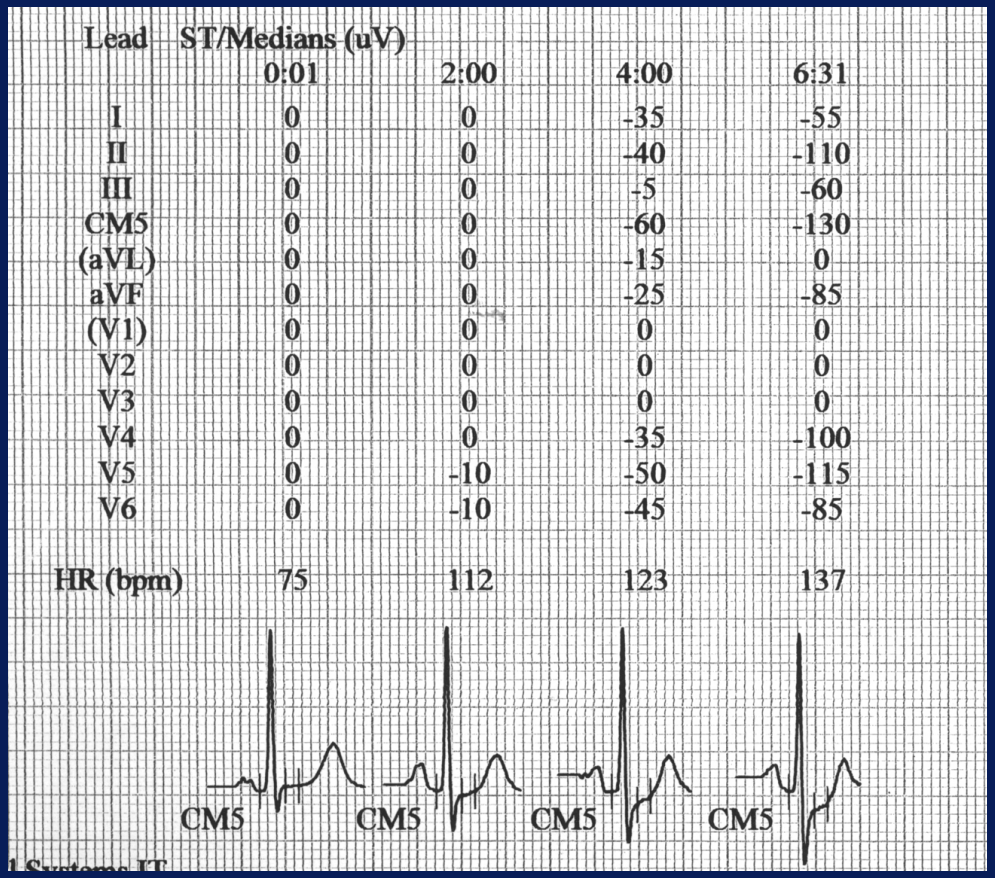
Reasons for test improvement: reduction in "false negative" test outcomes

- Identification of more patients with 1 and 2 vessel CAD
- High prevalence of correct classification of CAD patients with "equivocal" tests
- Identification of some CAD patients with truly negative standard tests

"EQUIVOCAL" ETTs: RELATION OF ST DEPRESSION TO HEART RATE IN CAD



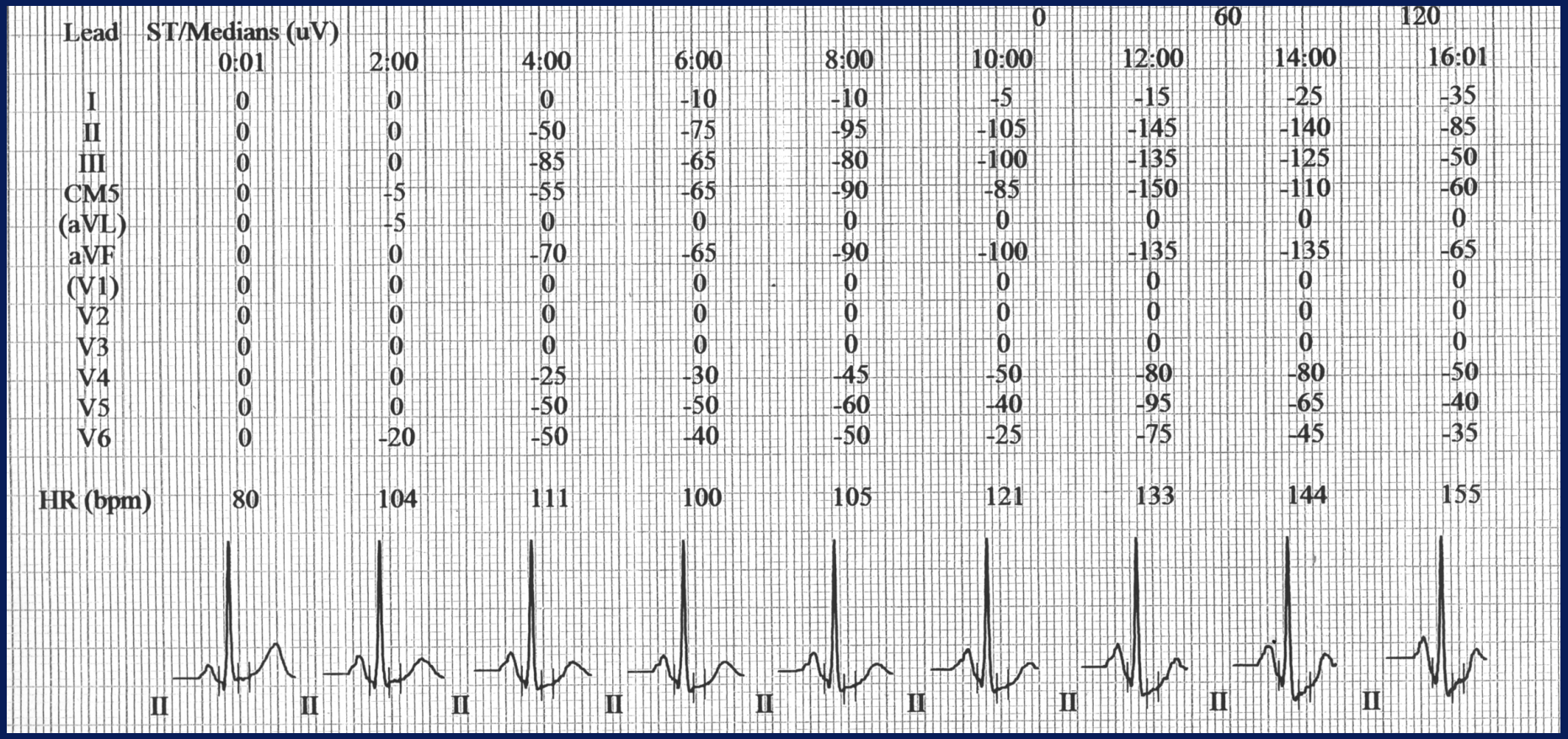
EQUIVOCAL EXERCISE ECG IN PATIENT WITH ISCHEMIA



Lead	ST/Medians (uV) 0:01	2:00	4:00	6:31
I	0	0	-35	-55
II	0	0	-40	-110
III	0	0	-5	-60
CM5	0	0	-60	-130
(aVL)	0	0	-15	0
aVF	0	0	-25	-85
(V1)	0	0	0	0
V2	0	0	0	0
V3	0	0	0	0
V4	0	0	-35	-100
V5	0	-10	-50	-115
V6	0	-10	-45	-85
HR (bpm)	75	112	123	137

ST/HR index = 130 μV/ 62 bpm = 2.1 μV/bpm

EQUIVOCAL EXERCISE ECG IN PATIENT WITHOUT CAD



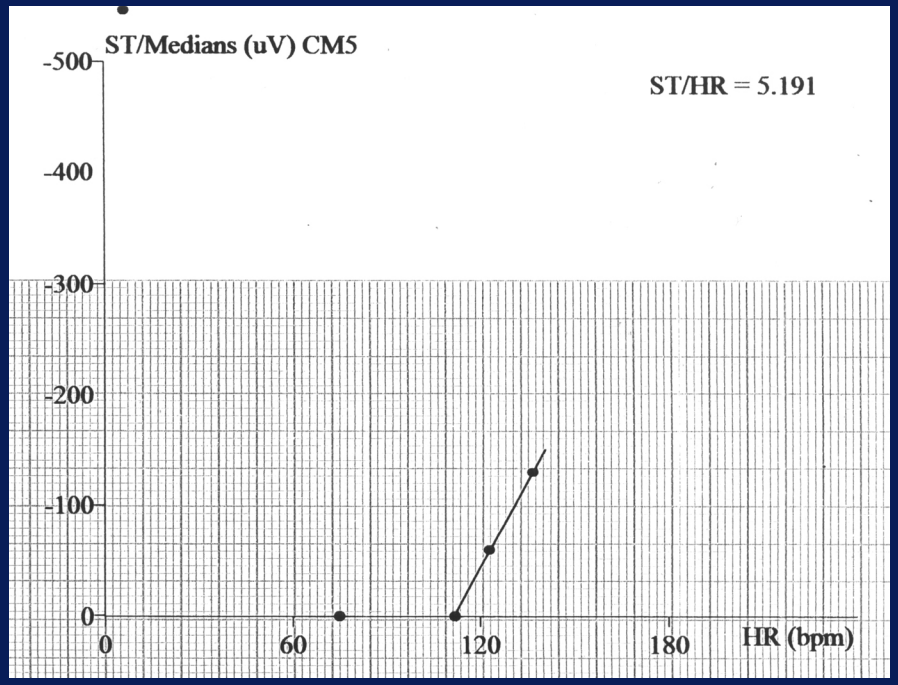
Lead	ST/Medians (uV)								
	0:01	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:01
I	0	0	0	-10	-10	-5	-15	-25	-35
II	0	0	-50	-75	-95	-105	-145	-140	-85
III	0	0	-85	-65	-80	-100	-135	-125	-50
CM5	0	-5	-55	-65	-90	-85	-150	-110	-60
(aVL)	0	-5	0	0	0	0	0	0	0
aVF	0	0	-70	-65	-90	-100	-135	-135	-65
(V1)	0	0	0	0	0	0	0	0	0
V2	0	0	0	0	0	0	0	0	0
V3	0	0	0	0	0	0	0	0	0
V4	0	0	-25	-30	-45	-50	-80	-80	-50
V5	0	0	-50	-50	-60	-40	-95	-65	-40
V6	0	-20	-50	-40	-50	-25	-75	-45	-35
HR (bpm)	80	104	111	100	105	121	133	144	155

0 60 120

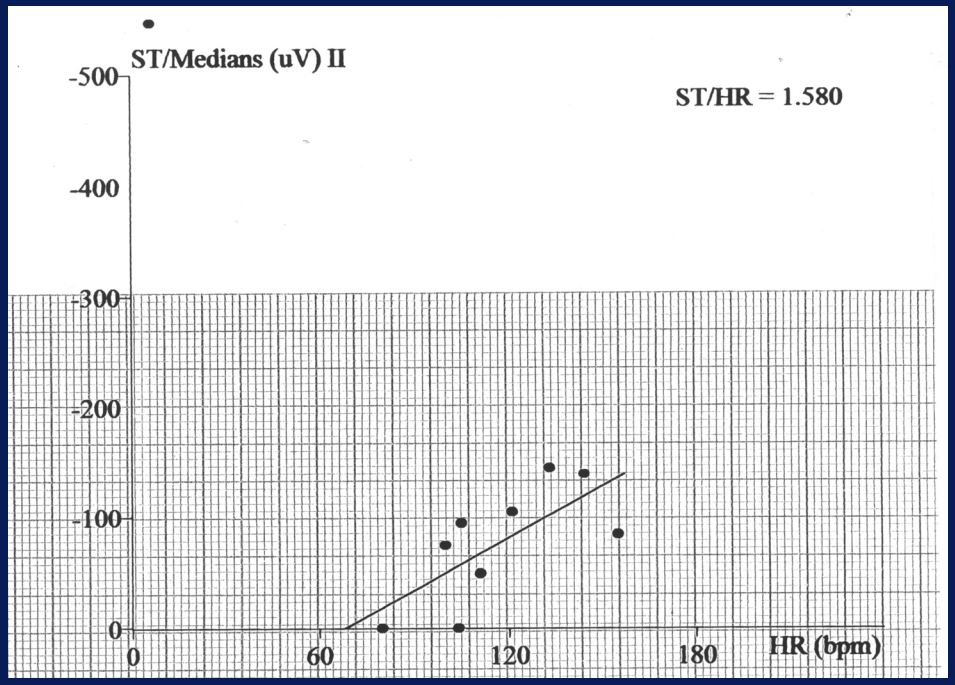
II II II II II II II II II

ST/HR index = 85 μV/ 75 bpm = 1.1 μV/bpm

LINEARITY OF EXERCISE INDUCED ISCHEMIC ST DEPRESSION

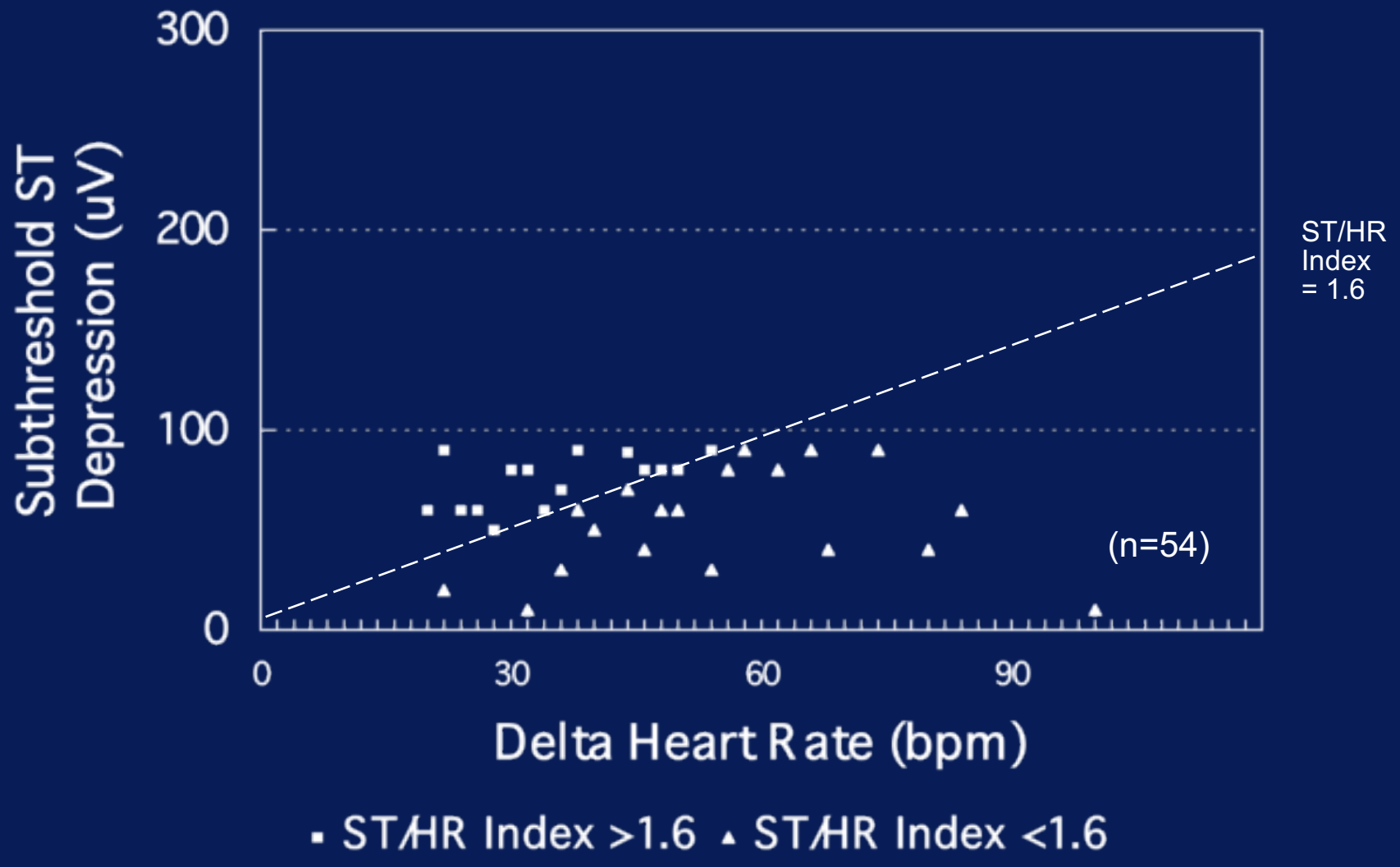


Ischemic



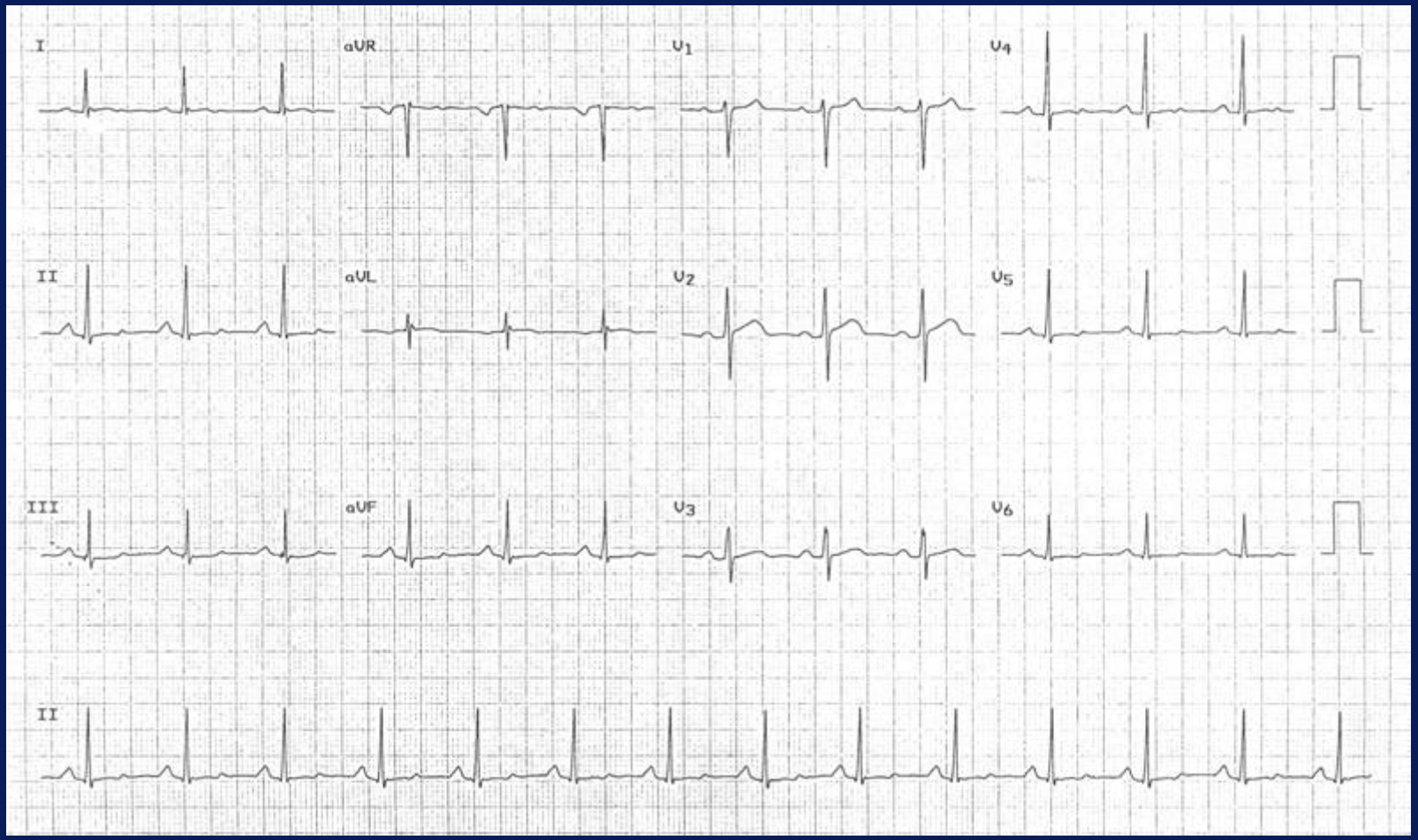
Non-ischemic

NEGATIVE ETTs: RELATION OF ST DEPRESSION TO HEART RATE IN CAD



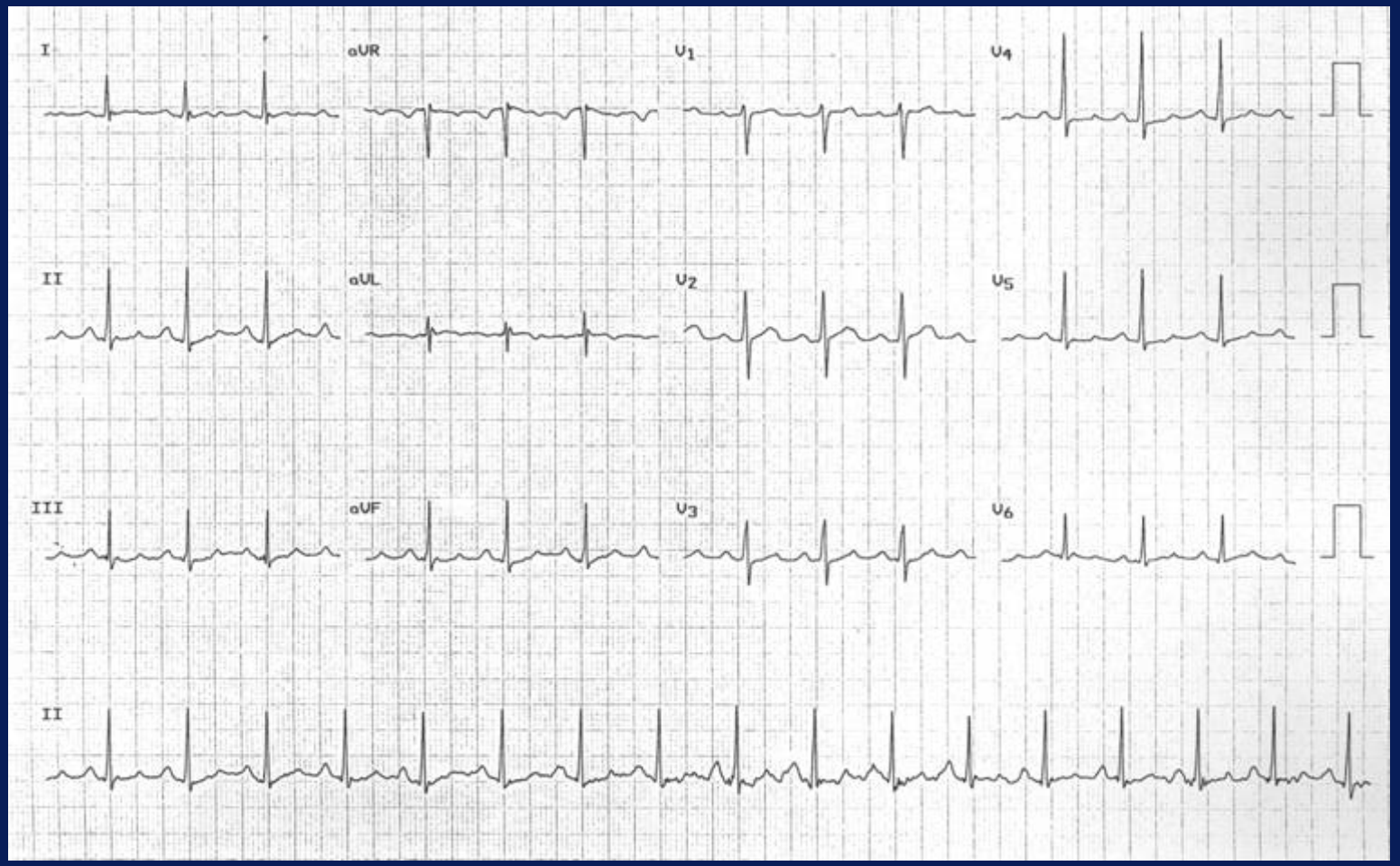
STANDING REST: 83 BPM, 116/68

No symptoms



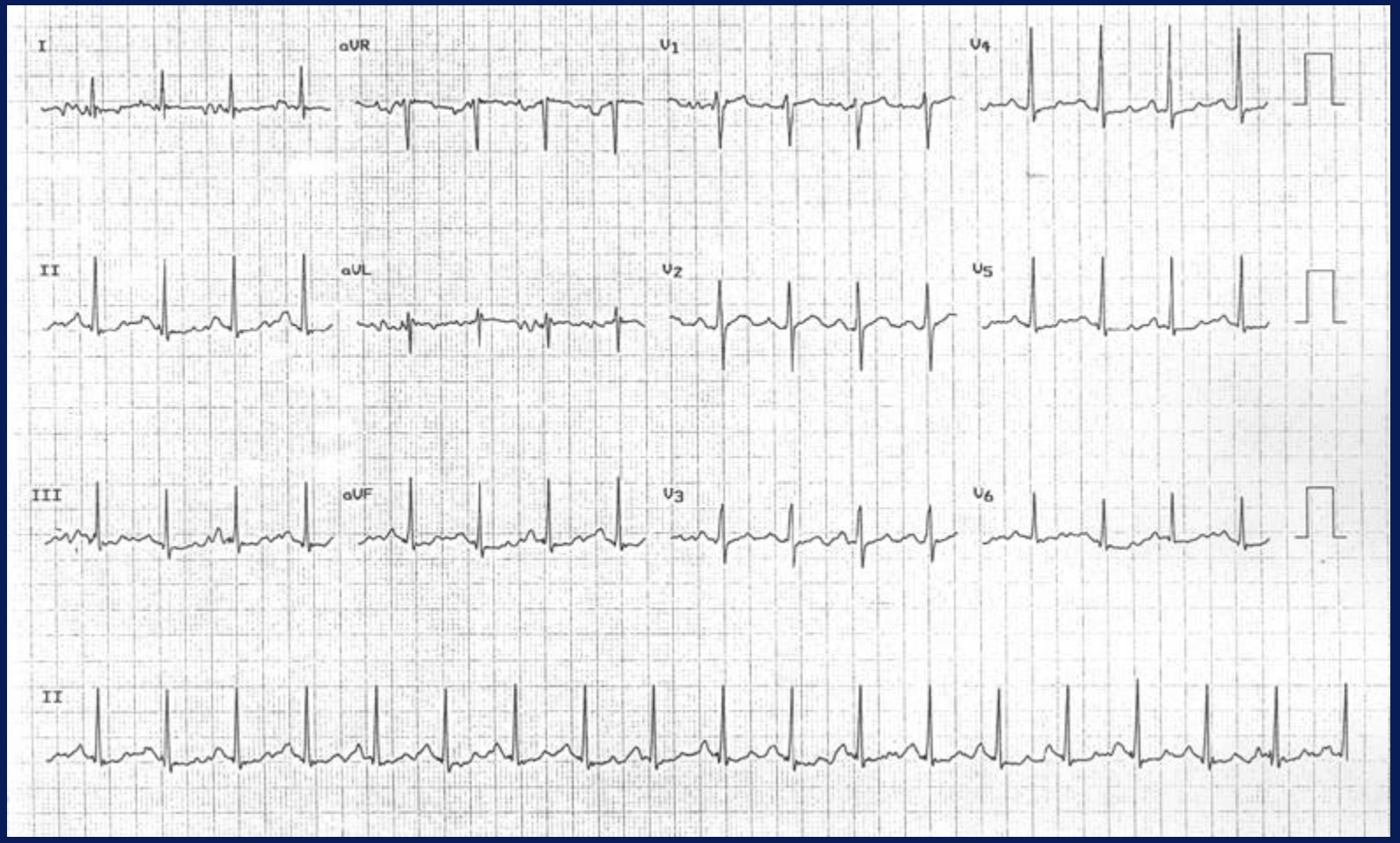
2 MIN 1.7 MPH, 10%: 100 BPM

Just prior to onset of angina



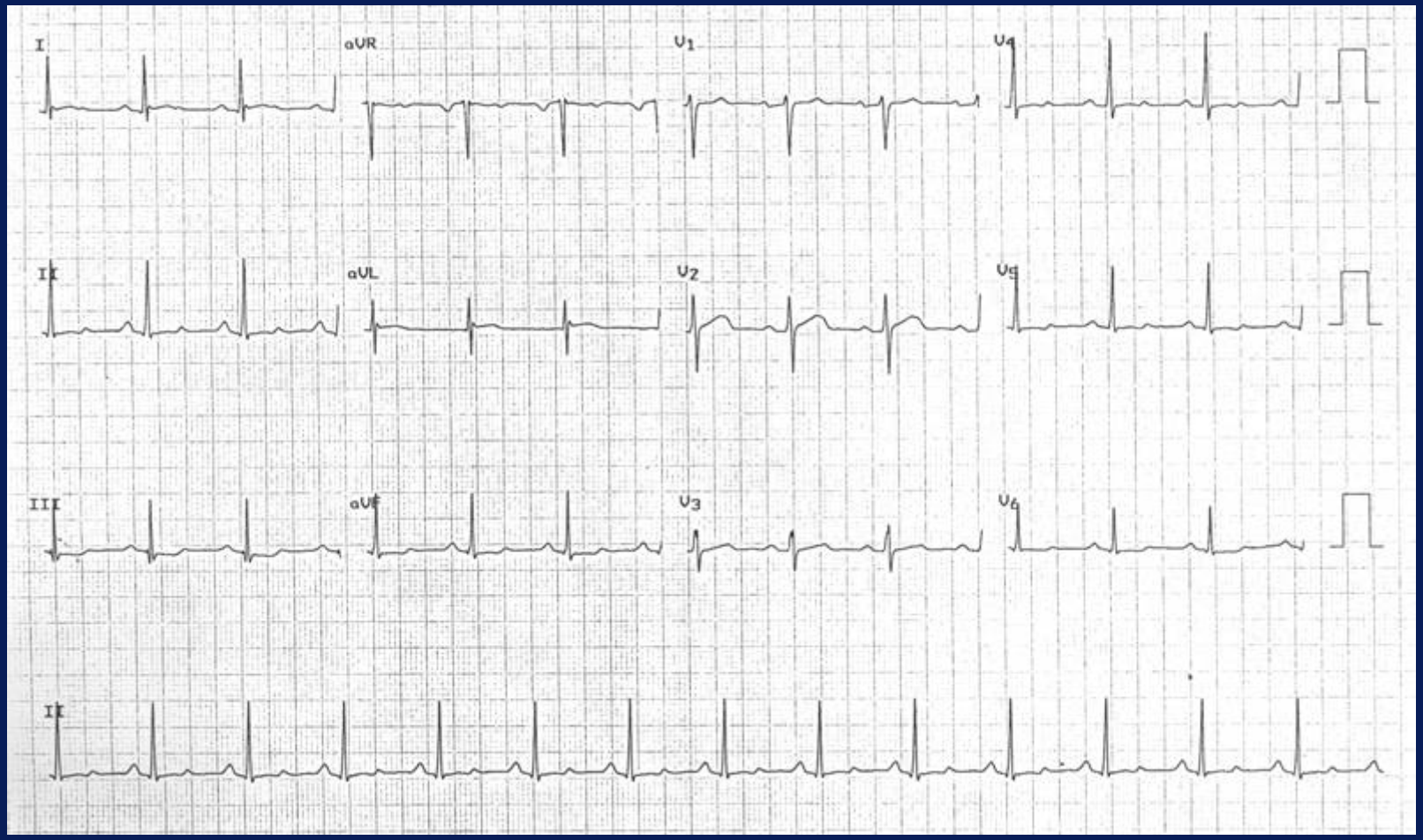
1 MIN 2.5 MPH, 12%: 111 BPM, 140/60

Exercise-limiting angina 7/10, 0.5 mm STD



3 MIN RECOVERY: 85 BPM

Resolving angina 2/10



PT WHJ: EXERCISE PERFORMANCE

PHASE	WORK LOAD	HR	BP	ST DEP
Upright control	0 mph 0 %	83	116/68	0
Peak exercise	2.5 mph 12 %	111	140/60	0.5 mm = 50 µV

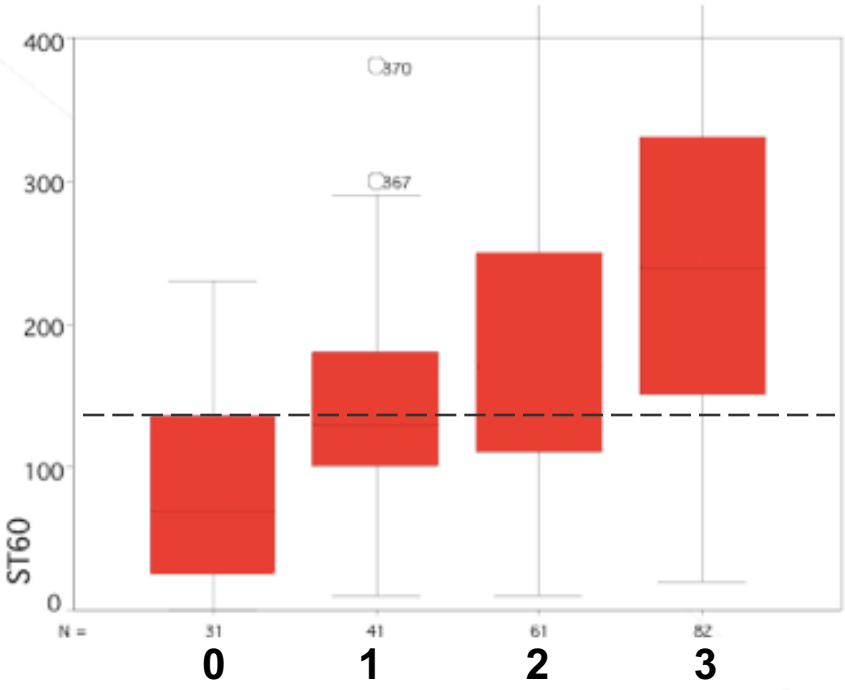
Δ HR =
28 bpm

Δ ST =
50 µV

ST/HR Index = 50/28 = 1.8 µV/bpm [>1.6]

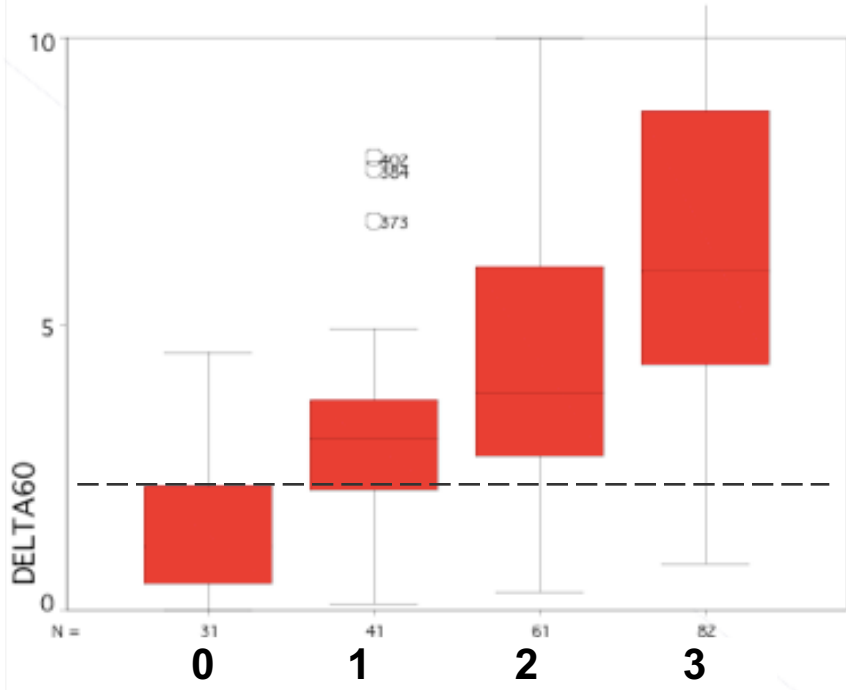
STD AND ST/HR INDEX IN RELATION TO PRESENCE AND EXTENT OF CAD

ST depression (uV)



p=ns

ST/HR Index (uV/bpm)

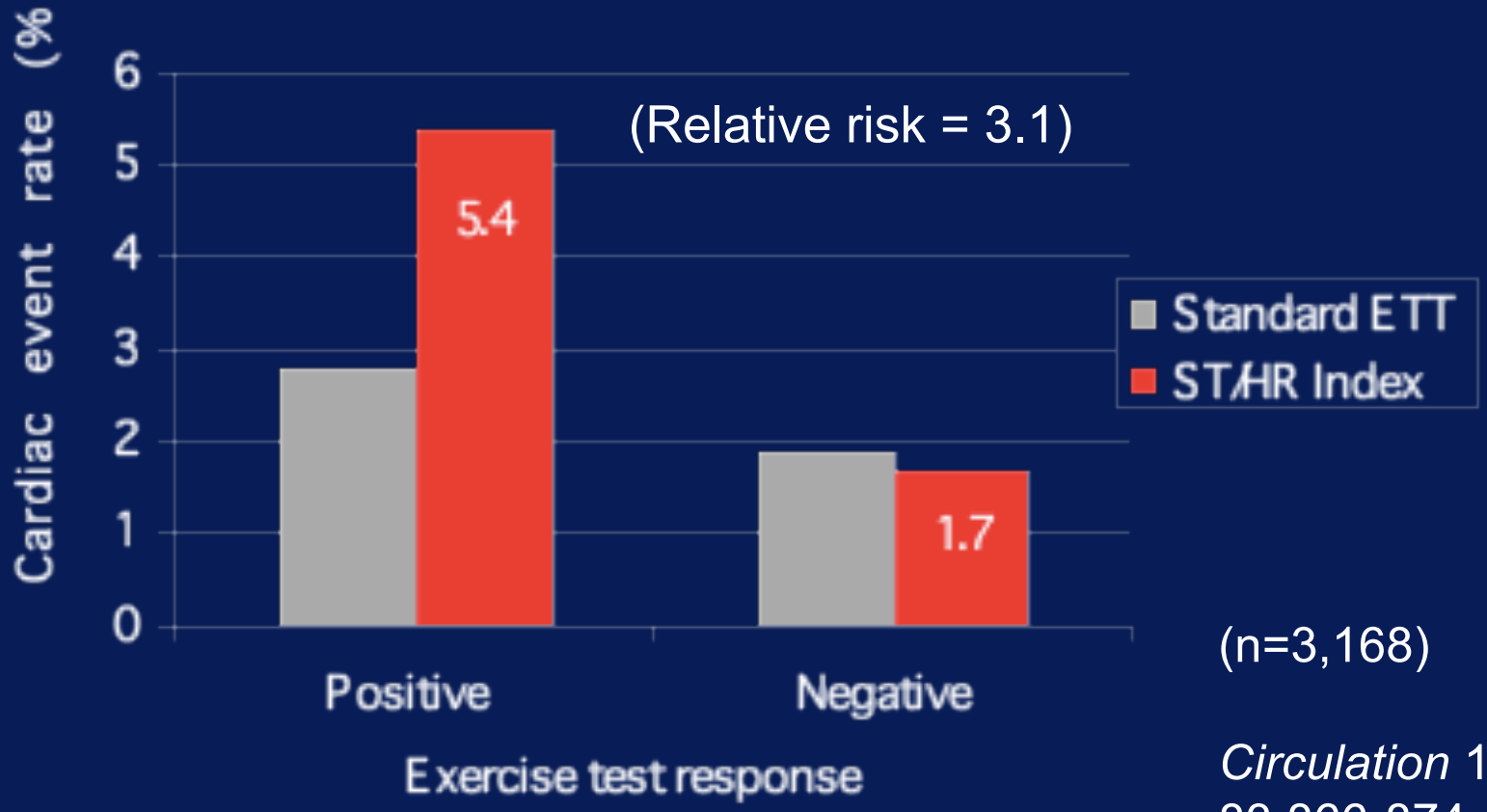


p<0.05

Extent of CAD (number of obstructed arteries)

FOUR YEAR CARDIAC EVENT RATE IN ASYMPTOMATIC FRAMINGHAM ADULTS

Absolute risk of cardiac events during 4-year follow-up predicted by standard ETT and by ST/HR index:

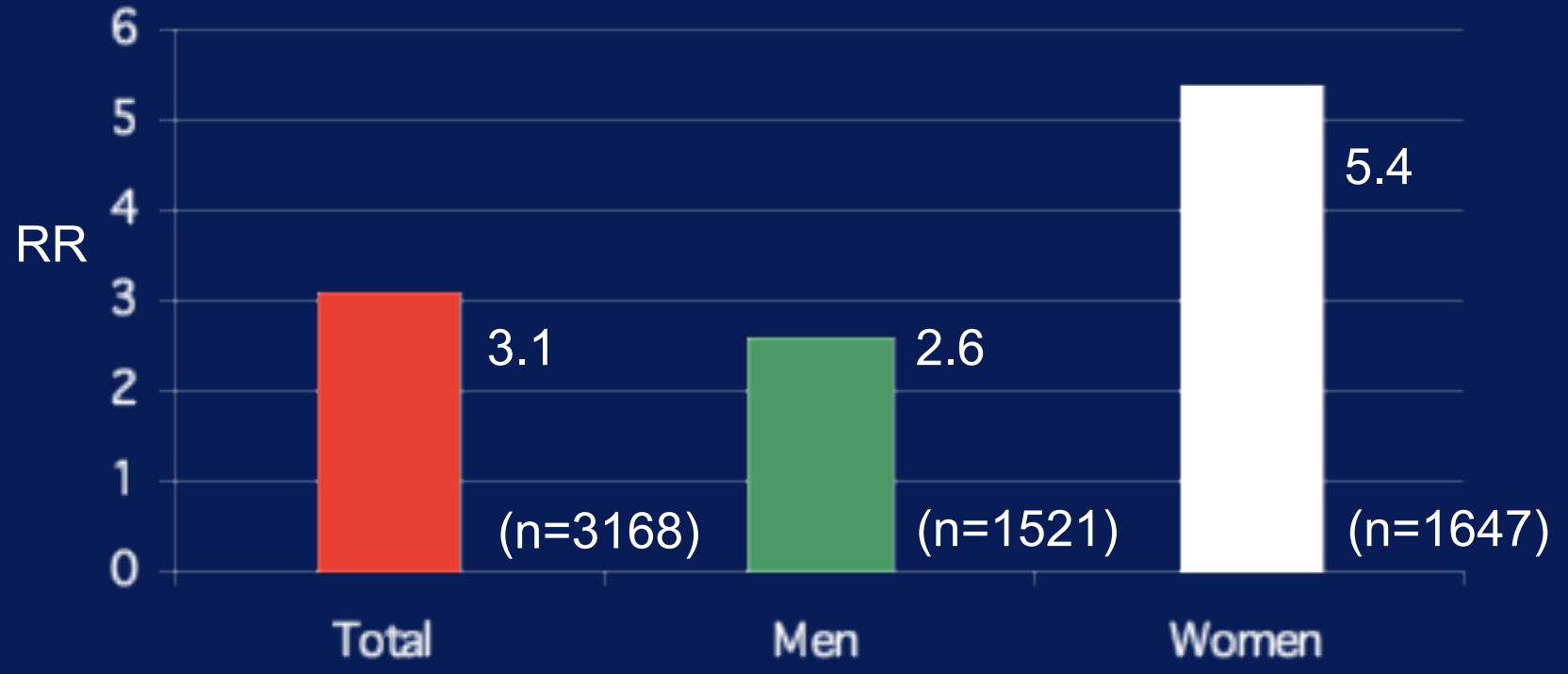


(n=3,168)

Circulation 1991 83:866-874

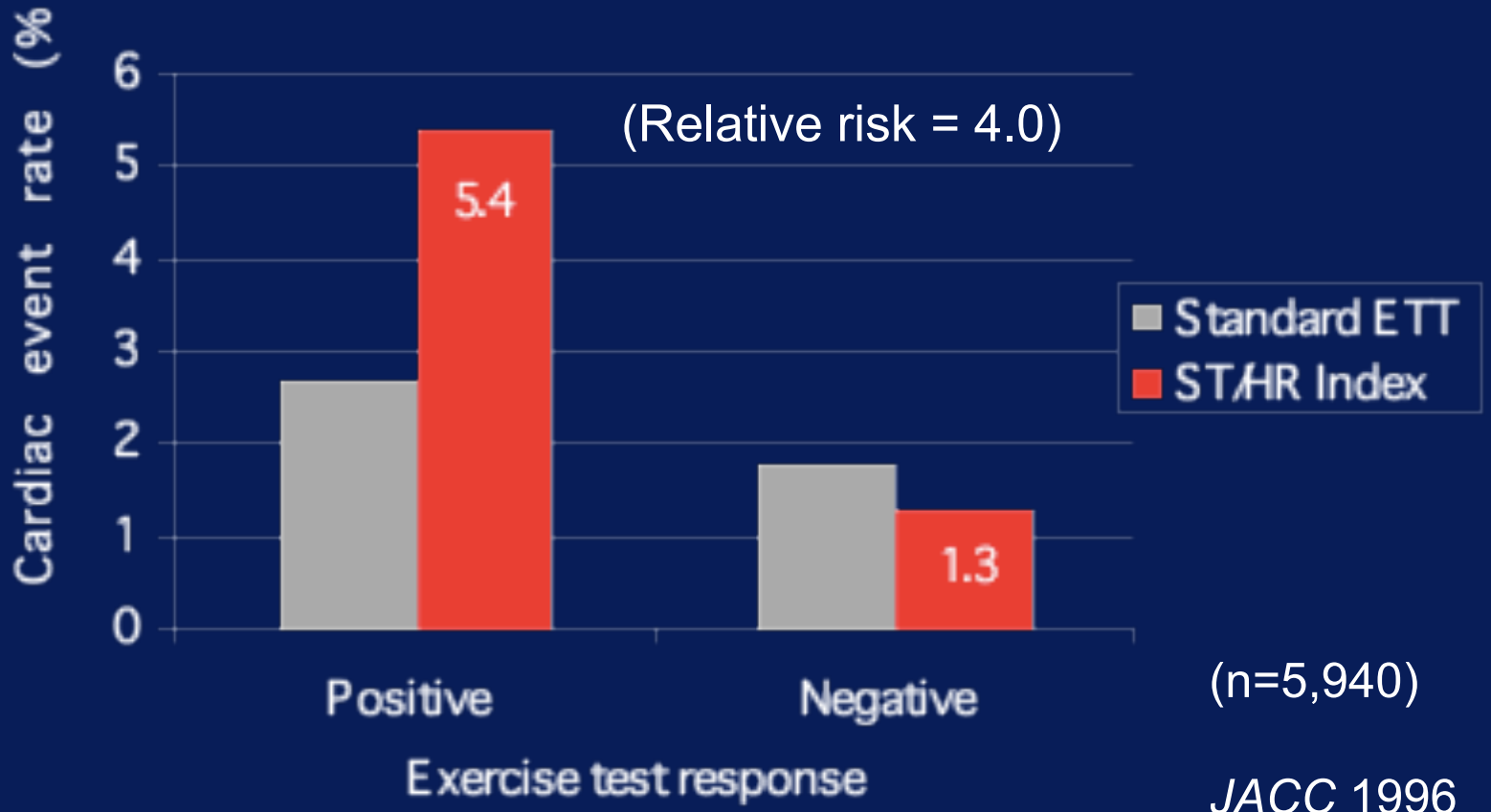
RELATIVE RISK OF EVENTS AMONG FRAMINGHAM MEN AND WOMEN

Relative risk of future cardiac events associated with ST/HR index>1.6 during 4 year follow-up, by sex:



SEVEN-YEAR CARDIAC MORTALITY IN ASYMPTOMATIC MrFIT USUAL CARE

Absolute risk of mortality during 7-year followup predicted by standard ETT and by ST/HR index:



(n=5,940)

JACC 1996
27:1437-1443

SUMMARY: HEART RATE AND THE ST SEGMENT DURING EXERCISE

- Simple heart rate adjustment of ST depression during exercise controls for the increasing metabolic severity of ischemia to clarify the underlying extent of disease
- Improvement of exercise test sensitivity with the ST/HR index results from reclassification of otherwise “equivocal” and even “negative” test responses, including increased identification of one and two-vessel disease in men and in women.
- The ST/HR index can increase the prognostic value of the exercise ECG by prediction of cardiac risk and mortality

FURTHER READING

- Kligfield P, Lauer M. Exercise electrocardiogram testing: beyond the ST segment. *Circulation* 114:2070-2082, 2006
- Kligfield P. Rethinking the exercise electrocardiogram (editorial). *Annals of Noninvasive Electrocardiology* 11:99-101, 2006
- Okin PM, Kligfield P. Heart rate adjustment of ST depression and performance of the exercise electrocardiogram: a critical evaluation. *Journal of the American College of Cardiology* 25:1726-1735, 1995