Physiology of Exercise Tests

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Key Points of Exercise Physiology

- Manual SBP measurement (not automated) most important for safety
- Adjust to clinical history
- No Age predicted Heart Rate Targets
- The BORG Scale of Perceived Exertion
- METs not Minutes
- Fit protocol to patient (RAMP)
- Avoid HV and cool down walk
- Use standard ECG analysis/ 3 minute recovery/ use scores
- Heart rate recovery
- Expired Gas Analysis?

BORG SCALE

6

7 Very, very light

8

9 Very light

10

11 Fairly light

12

13 Somewhat hard

14

15 Hard

16

17 Very hard

18

19 Very, very hard

20

Symptom-Sign Limited Testing Endpoints - When to stop !

- Dyspnea, fatigue, chest pain
- Systolic blood pressure drop
- ECG--ST changes, arrhythmias
- Physician Assessment
- Borg Scale (17 or greater)

How to read an Exercise ECG

- Good skin prep
- PR isoelectric line
- Not one beat
- Three consistent complexes
- Averages can help
- Three minute recovery

Types of Exercise

- Isometric (Static)
  - weight-lifting
  - pressure work for heart, limited cardiac output, proportional to effort
- Isotonic (Dynamic)
  - walking, running, swimming, cycling
  - Flow work for heart, proportional to external work
- Mixed

Oxygen Consumption During Dynamic Exercise Testing

There are Two Types to Consider:

- Myocardial (MO_2)
  - Internal, Cardiac
- Ventilatory (VO_2)
  - External, Total Body

Myocardial (MO_2)

- Coronary Flow x Coronary a - VO2 difference
- Wall Tension (Pressure x Volume, Contractility, Stroke Work, HR)
- Systolic Blood Pressure x HR
  - Angina and ST Depression usually occurs at same Double Product in an individual

    ** Direct relationship to VO2 is altered by beta-blockers, training,...

Problems with Age-Predicted Maximal Heart Rate

- Which Regression Formula? (2YY - .Y x Age)
- Big scatter around the regression line
  - poor correlation [-0.4 to -0.6]
- One SD is plus/minus 12 bpm
- Confounded by Beta Blockers
- A percent value target will be maximal for some and sub-max for others
- Borg scale is better for evaluating Effort
- Do Not Use Target Heart Rate to Terminate the Test or as the Only Indicator of Effort or adequacy of test

Myocardial (MO_2)

- Systolic Blood Pressure x HR
  - SBP should rise > 40 mmHg
  - Drops are ominous (Exertional Hypotension)
  - Diastolic BP should decline

Ventilatory (VO_2)

- Cardiac Output x a-VO_2 Difference
- VE x (% Inspired Air Oxygen Content - Expired Air Oxygen Content)
- External Work Performed

- ****Direct relationship with Myocardial O_2 demand and Work is altered by beta-blockers, training,...

VO2

THE FICK EQUATION

$$VO_2 = C.O. \times C(a\text{-}v)O_2$$

$$C(a\text{-}v)O_2 \sim k$$

then, $VO_2 \sim C.O.$

What is a MET?

- Metabolic Equivalent Term
- 1 MET = "Basal" aerobic oxygen consumption to stay alive = 3.5 ml O2 /Kg/min
- Actually differs with thyroid status, post exercise, obesity, disease states
- But by convention just divide ml O2/Kg/min by 3.5

Key MET Values (part 1)

- 1 MET = "Basal" = 3.5 ml O2 /Kg/min
- 2 METs = 2 mph on level
- 4 METs = 4 mph on level
- < 5METs = Poor prognosis if < 65;
  - limit immediate post MI;
  - cost of basic activities of daily living

Key MET Values (part 2)

- 10 METs = As good a prognosis with medical therapy as CABS
- 13 METs = Excellent prognosis, regardless of other exercise responses
- 16 METs = Aerobic master athlete
- 20 METs = Aerobic athlete

Calculation of METs on the Treadmill

$$\text{METs} = \frac{\text{Speed} \times [0.1 + (\text{Grade} \times 1.8)] + 3.5}{3.5}$$

Calculated automatically by Device!

Note: Speed in meters/minute conversion = MPH x 26.8

Grade expressed as a fraction

METs---not Minutes
(Report Exercise Capacity in METs)

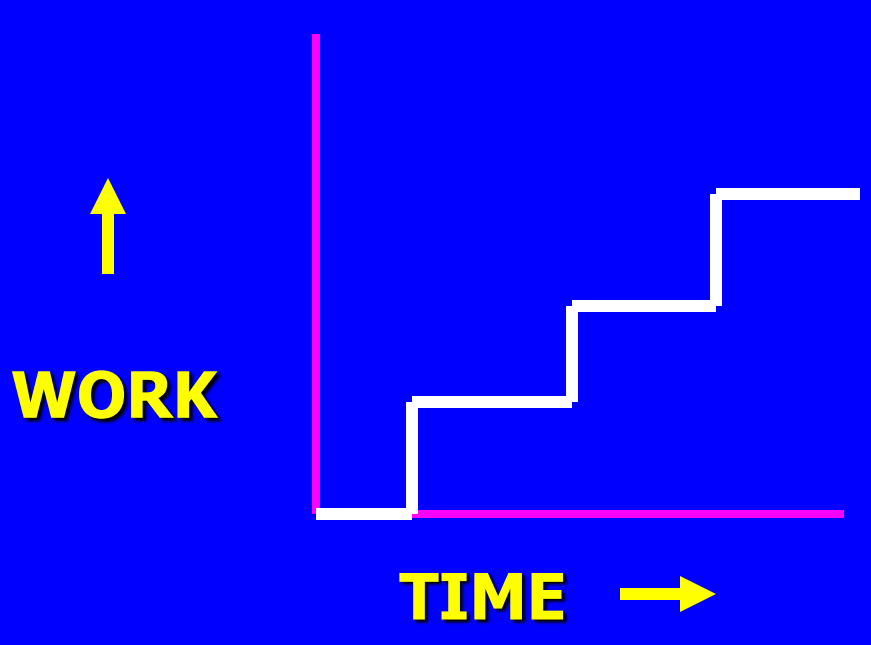
- Can compare results from any mode or Testing Protocol
- Can Optimize Test by Individualizing for Patient
- Can adjust test to 8-10 minute duration (aerobic capacity--not endurance)
- Can use prognostic power of METs

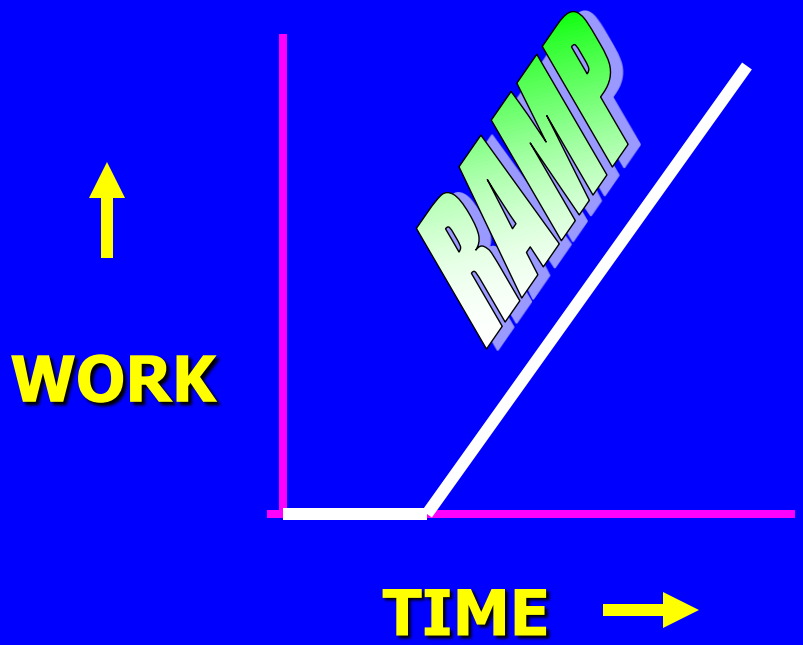
Estimated vs Measured METs

- All Clinical Applications based on Estimated
- Estimated Affected by:
  - Habituation (Serial Testing)
  - Holding on
  - Deconditioning and Disease State
- Measured Requires a Mouthpiece and Delicate Equipment
- Measured More Accurate and Permits measurement of Gas Exchange Anaerobic Threshold and Other Mxments (VE/VCO_2)
- Prognostic in CHF and Transplantation

WORK

TREADMILL





Why Ramp?

Started with Research for AT and ST/HR but clinicaly helpful

- Individualized test Using Prior Test, history or Questionnaire
- Linear increase in heart rate
- Improved prediction of METs
- Nine-minute duration for most patients
- Requires special Treadmill controller or manual control by operator

Should Heart Rate Drop in Recovery be added to ET?

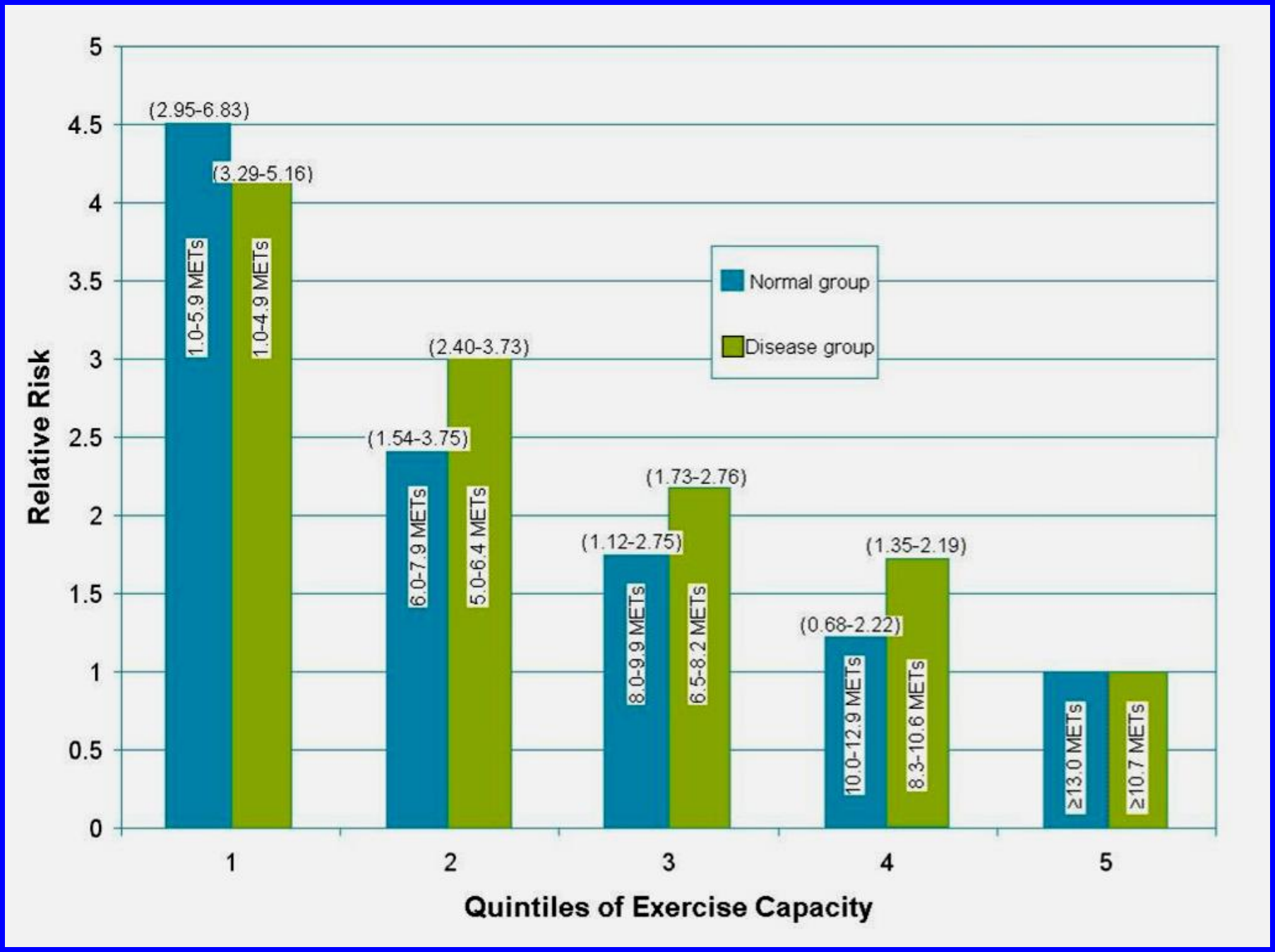
- Long known as a indicator of fitness: perhaps better for assessing physical activity than METs
- Recently found to be a predictor of prognosis after clinical treadmill testing
- Does not predict angiographic CAD
- Studies to date have used all-cause mortality and failed to censor

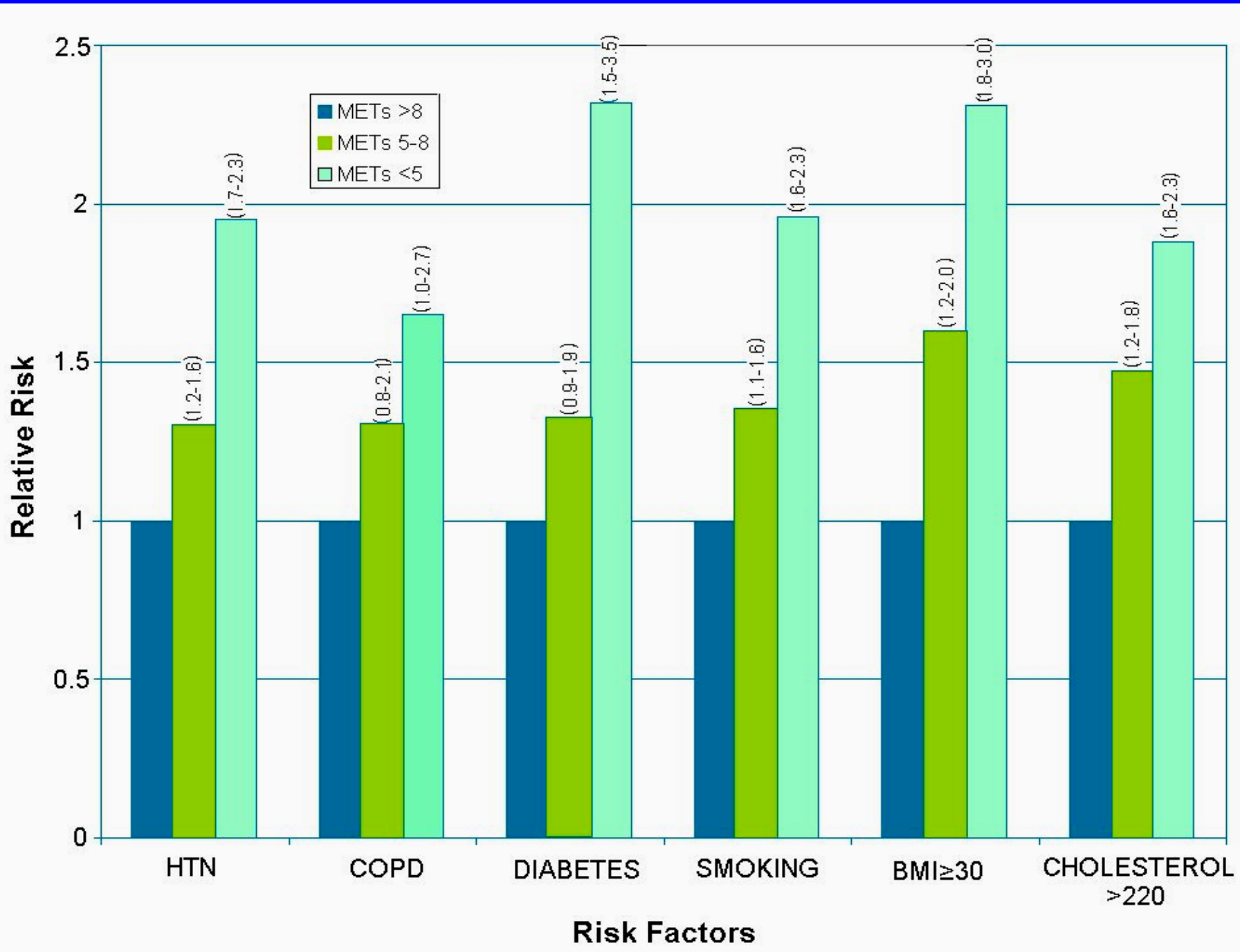
Heart Rate Drop in Recovery

- Probably not more predictive than Duke Treadmill Score or METs
- Studies including censoring and CV mortality needed
- Should be calculated along with Scores as part of all treadmill tests

Heart Rate Drop in Recovery vs METs

- **10 to 15%** increase in survival per MET
- Can be increased by **25%** by a training program
- What about Heart Rate Recovery???


Relative Risk
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
(2.95-6.83)
(3.29-5.16)
(2.40-3.73)
(1.54-3.75)
(1.73-2.76)
(1.12-2.75)
(1.35-2.19)
(0.68-2.22)
1.0-5.9 METs
1.0-4.9 METs
6.0-7.9 METs
5.0-6.4 METs
8.0-9.9 METs
6.5-8.2 METs
10.0-12.9 METs
8.3-10.6 METs
≥13.0 METs
≥10.7 METs
Normal group
Disease group
1
2
3
4
5
Quintiles of Exercise Capacity


METs >8
METs 5-8
METs <5
Relative Risk
2.5
2
1.5
1
0.5
0
(1.2-1.6)
(1.7-2.3)
(0.8-2.1)
(1.0-2.7)
(0.9-1.9)
(1.5-3.5)
(1.1-1.6)
(1.6-2.3)
(1.2-2.0)
(1.8-3.0)
(1.2-1.8)
(1.6-2.3)
HTN
COPD
DIABETES
SMOKING
BMI≥30
CHOLESTEROL >220
Risk Factors

Maximal Heart Rate vs METs

- Diagnosis vs Prognosis

AHA/ACC Exercise Testing Guidelines: Recommendations for Exercise Testing

- Diagnosis CAD
- Prognosis with symptoms/CAD
- After MI
- Using Ventilatory Gas Analysis
- Special Groups

AHA/ACC Exercise Testing Guidelines: Recommendations for Exercise Testing

- Special Groups:
  - Pre- and Post-Revascularization
  - Women
  - Asymptomatic
  - Pre-surgery
  - Valvular Heart Disease
  - Cardiac Rhythm Disorders

The ACC/AHA Guidelines for the Diagnostic Use of the Standard Exercise Test

- **Class I (Definitely appropriate) -** Adult males or females (including RBBB or < 1mm resting ST depression) with an intermediate pre-test probability of coronary artery disease based on gender, age and symptoms (specific exceptions are noted under Class II and III below).

- **Class IIa (Probably appropriate) -** Patients with vasospastic angina.

Pre Test Probability of Coronary Disease by Symptoms, Gender and Age

Age	Gender	Typical/Definite Angina Pectoris	Atypical/Probable Angina Pectoris	Non-Anginal Chest Pain	Asymptomatic
30-39	Males	Intermediate	Intermediate	low (<10%)	Very low (<5%)
30-39	Females	Intermediate	Very Low (<5%)	Very low	Very low
40-49	Males	High (>90%)	Intermediate	Intermediate	low
40-49	Females	Intermediate	Low	Very low	Very low
50-59	Males	High (>90%)	Intermediate	Intermediate	Low
50-59	Females	Intermediate	Intermediate	Low	Very low
60-69	Males	High	Intermediate	Intermediate	Low
60-69	Females	High	Intermediate	Intermediate	Low

High = >90% Intermediate = 10-90% Low = <10%

Very Low = <5%

Diagnostic Use, continued:

- **Class IIb (Maybe appropriate) –**
  - ♥ Patients taking Digoxin with less than 1 mm resting ST depression.
  - ♥ Patients with ECG criteria for left ventricular hypertrophy with less than 1 mm ST depression.
  - ♥ Patients with a high pre-test probability of coronary artery disease by age, symptoms and gender.
  - ♥ Patients with a low pre-test probability of CAD by age, symptoms and gender.

Diagnostic Use, continued:

- **Class III (Not appropriate) -**
- 1. To use the ST segment response in the diagnosis of coronary artery disease in patients who demonstrate the following baseline ECG abnormalities:
  - pre-excitation (WPW) syndrome;
  - electronically paced ventricular rhythm;
  - more than one millimeter of resting ST depression;
  - LBBB
- 2. To use the ST segment response in the diagnosis of coronary artery disease in MI patients

Comparison of Tests for Diagnosis of CAD

Grouping	# of Studies	Total # Patients	Sens	Spec	Predictive Accuracy
Standard ET	147	24,047	68%	77%	**73%**
• **ET Scores**	24	11,788			**80%**
• **Score Strategy**	2	>1000	85%	92%	**88%**
Thallium Scint	59	6,038	85%	85%	**85%**
SPECT	16+14	5,272	88%	72%	**80%**
Adenosine SPECT	10+4	2,137	89%	80%	**85%**
Exercise ECHO	58	5,000	84%	75%	**80%**
Dobutamine ECHO	5	<1000	88%	84%	**86%**
Dobutamine Scint	20	1014	88%	74%	**81%**
Electron Beam Tomography (EBCT)	16	3,683	60%	70%	**65%**

Variable	Circle response	Sum
Maximal Heart Rate	Less than 100 bpm = 30	
	100 to 129 bpm = 24	
	130 to 159 bpm =18	
	160 to 189 bpm =12	
	190 to 220 bpm =6	
Exercise ST Depression	1-2mm =15	
	> 2mm =25	
Age	>55 yrs =20	
	40 to 55 yrs = 12	
Angina History	Definite/Typical = 5	
	Probable/atypical =3	
	Non-cardiac pain =1	
Hypercholesterolemia?	Yes=5	
Diabetes?	Yes=5	
Exercise test	Occurred =3	
induced Angina	Reason for stopping =5	
	Total Score:	

Males

Choose only one per group

<40=low prob

40-60= intermediate probability

>60=high probability

Women

Variable	Circle response	Sum
Maximal Heart	Less than 100 bpm = 20	
Rate (x4)	100 to 129 bpm = 16	
	130 to 159 bpm =12	
	160 to 189 bpm =8	
	190 to 220 bpm =4	
Exercise ST	1-2mm =6	
Depression (x2)	> 2mm =10	
Age	>65 yrs =25	
(x5)	50 to 65 yrs = 15	
Angina History (x2)	Definite/Typical = 10	
	Probable/atypical =6	
	Non-cardiac pain =2	
Smoking? (x2)	Yes=10	
Diabetes? (x2)	Yes=10	
Exercise test	Occurred =9	
induced Angina (x3)	Reason for stopping =15	
Estrogen Status	Positive=-5, Negative=5	
	Total Score	

Choose only one per group

<37=low prob

37-57= intermediate probability

>57=high probability

The ACC/AHA Guidelines for the Prognostic Use of the Standard Exercise Test

- Indications for Exercise Testing to Assess Risk and prognosis in patients with symptoms or a prior history of coronary artery disease:
- Class I. ***Should be used***:
  - Patients undergoing initial evaluation with suspected or known CAD. Specific exceptions are noted below in Class IIb.
  - Patients with suspected or known CAD previously evaluated with significant change in clinical status.

Prognostic Use, continued:

- Class IIb. ***Maybe Appropriate for:***
  - Patients who demonstrate the following ECG abnormalities:
    - Pre-excitation (WPW) syndrome;
    - Electronically paced ventricular rhythm;
    - More than one millimeter of resting ST depression; and
    - LBBB.
  - Patients with a stable clinical course who undergo periodic monitoring to guide management

Prognostic Use, continued:

- Class IIa. ***Probably Appropriate:***
  - ***None***
- Class III***. Should not be used for prognostication:***
  - Patients with severe comorbidity likely to limit life and/or consideration for revascularization procedures

Endpoints for Prediction of Prognosis

- Why is this even an issue??
- Confusion
- All-cause certainly best for interventional studies
- CV mortality more appropriate outcome for CV tests

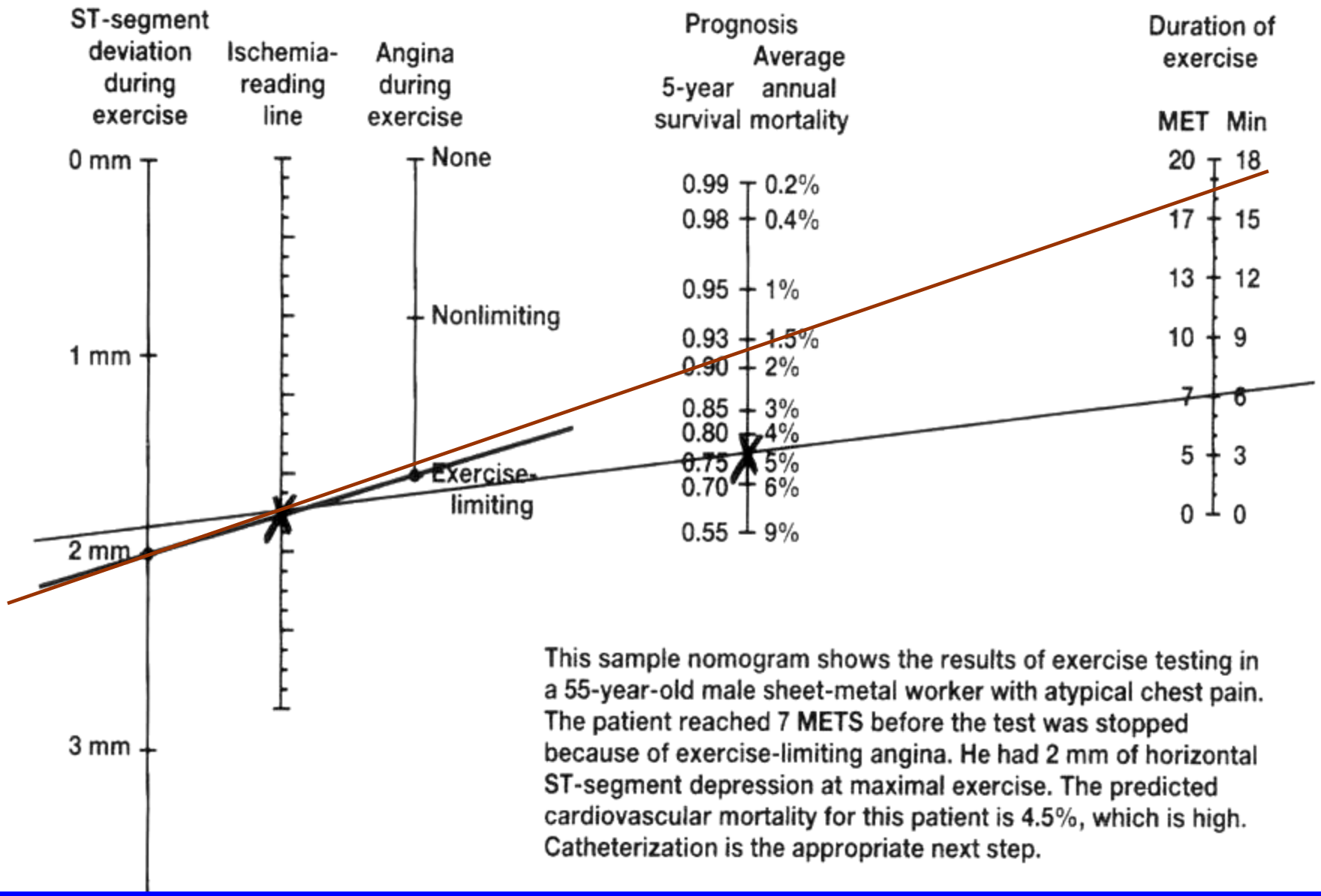
DUKE Treadmill Score for Stable CAD

METs - 5 X [mm E-I ST Depression] -
4 X [Treadmill Angina Index]

Nomogram

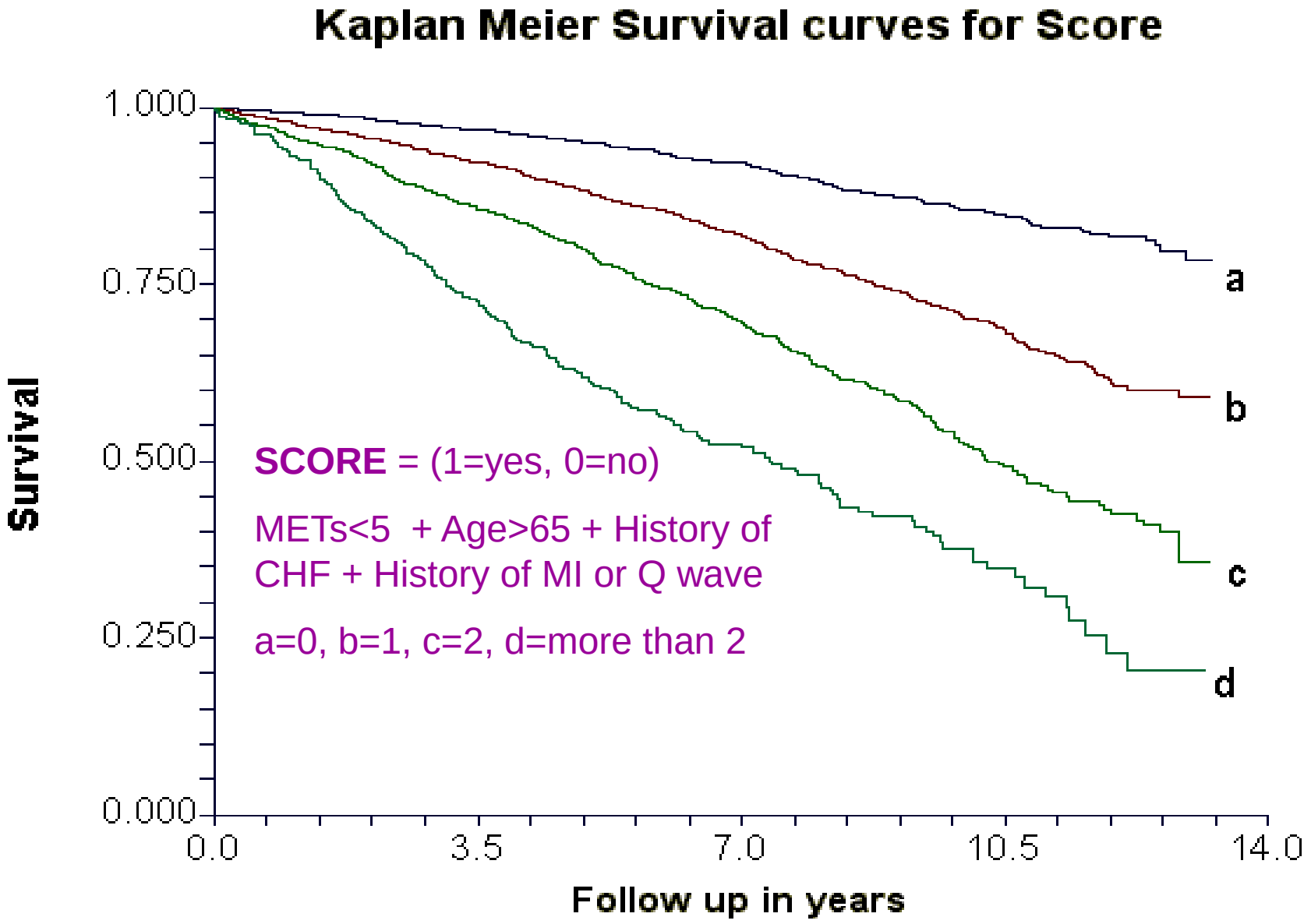
E-I = Exercise Induced

Duke Treadmill Score (uneven lines, elderly?)



This sample nomogram shows the results of exercise testing in a 55-year-old male sheet-metal worker with atypical chest pain. The patient reached 7 METS before the test was stopped because of exercise-limiting angina. He had 2 mm of horizontal ST-segment depression at maximal exercise. The predicted cardiovascular mortality for this patient is 4.5%, which is high. Catheterization is the appropriate next step.

“All-comers” prognostic score



But Can Physicians do as well as the Scores?

- 954 patients - clinical/TMT reports
- Sent to 44 expert cardiologists, 40 cardiologists and 30 internists
- Scores did better than all three but was most similar to the experts

Key Points of Exercise Testing

- Manual SBP measurement (not automated) most important for safety
- Adjust to clinical history (couch potatoes)
- No Age predicted Heart Rate Targets
- The BORG Scale of Perceived Exertion
- METs not Minutes
- Fit protocol to patient (RAMP)
- Avoid HV and cool down walk
- Use standard ECG analysis/ 3 minute recovery/ use scores
- Heart rate recovery
- Expired Gas Analysis?

Question 1

What is the most important prognostic measurement from the exercise test?

1. BORG scale estimate
2. ST depression
3. Exercise time
4. Exercise capacity

Question 2

What is the most appropriate indicator of a maximal effort?

1. BORG scale
2. ST depression
3. Heart rate
4. Exercise capacity

All references are available as pdf files on www.cardiology.org along with scores and sample report generator