TREADMILL EXERCISE TESTING

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Disclosures: None

CLINICAL USES OF EXERCISE TESTS
• Evaluation of chest pain syndromes
  - Effort angina: stable, crescendo
  - Atypical chest pain, cardiac origin
  - Atypical chest pain, noncardiac origin
• Assessment of effort tolerance
  - Post-myocardial infarction
  - Post-revascularization
  - Valve disease
• Chronotropic competence
• Evaluation of rate control in AF
• Evaluation of Rx of CAD (medical, surgical, post-PCI)

CLINICAL USES OF EXERCISE TESTS
• Evaluation of blood pressure Rx in hypertension
• Detection of myocardial ischemia in pts at high risk for CAD
• Exercise prescription and risk-stratification post-MI
• Detection of exercise arrhythmias
  - Due to myocardial ischemia
  - Symptoms of cerebral hypoperfusion with exercise
• Survivors of out-of-hospital cardiac arrest
CONTRAINDICATIONS TO MAXIMUM EXERCISE

• Unstable angina pectoris
• Baseline uncontrolled ventricular arrhythmias
• ECG suspicious for recent MI
ST SEGMENT RESPONSES DURING EXERCISE TESTING: PATHOPHYSIOLOGY

• Primary in myocardial oxygen demand (usually produces ST depression)
• Primary in myocardial oxygen supply (can produce ST elevation)

ECG RESPONSES DURING EXERCISE TESTING

• ST segment abnormalities
  - Depression (downsloping, horizontal, slowly upsloping)
  - Elevation
  - Scooping
  - Alternans
• ST depression in exercise PVCs

Positional ST-T wave abnormalities
Evolution of downsloping ST-T segment response

Pseudo-ST depression due to baseline artifact
Pseudo-ST elevation due to artifact
ST-T alternans

PR DEPRESSION WITH PROMINENT T-wave
54 y.o. male - recent admission for unstable angina; isordil, β-blocker on discharge

0 seconds recovery. Exercise duration 3 minutes.

40 mm Hg drop in systolic pressure

3 minutes recovery
45 y.o. woman with chest pain and hypertension

ECG 4.5 min

REC 3 min
### ECG RESPONSES DURING EXERCISE TESTING

- T wave abnormalities, isolated
  - Inversion
  - Normalization
    - Prevalence: pts with CAD = 27%, pts without CAD = 57%
    - In over 90% of pts with CAD, exercise test will show evidence of ischemia
      - In pts without CAD, exercise test will be normal
    - T wave normalization does not interfere with ischemic response
      - May indicate myocardial viability
        - † amplitude ("coronary Ts")

### P ABNORMALITIES WITH EXERCISE

REST PEAK EFFORT

### ECG RESPONSES DURING EXERCISE TESTING

- U waves
  - Inversion
  - Enhancement
- QT dispersion
- Axis shifts
- Rate dependent bundle branch block
- QRS duration changes
- † in P wave duration (LA) or amplitude (RA) in II
EXERCISE TEST RESPONSES PREDICTING SEVERE CAD

- ST segments: downsloping, elevated
- Early onset of ischemic ECG changes (1st 3 min)
- Prolonged duration of ischemic ECG changes in recovery (> 7 min)
- Hypotension associated with evidence of ischemia

CORRELATES OF EXERCISE-INDUCED ST SEGMENT ELEVATION

- High-grade proximal obstruction without collaterals
- Viability in infarct area (86% + predictive accuracy) (hibernating myocardium)
- Regional wall-motion abnormality, especially anterior wall (large infarction)
- Coronary artery spasm
- High incidence of 100% occlusion of an infarct-related artery (75% of pts) and collateral flow (93% of pts)
- No relationship to extent (number of vessels) of CAD

EXERCISE TEST RESPONSES NOT HELPFUL IN PREDICTING SEVERE CORONARY ARTERY DISEASE

- Inappropriate sinus tachycardia
- Failure of heart rate to increase appropriately
- Failure of systolic blood pressure to rise
- Rise in diastolic blood pressure
- Ischemic ECG changes in exercise vs recovery
- Ventricular arrhythmias at high heart rate
- Atrial arrhythmias
- Bradyarrhythmias
Inverted U waves during exercise testing

Peak Ex
Recovery 15 sec

U WAVE ENHANCEMENT WITH EXERCISE

Site of prominent U-waves

<table>
<thead>
<tr>
<th>Site of prominent U-waves</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>+ prediction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limb leads</td>
<td>19</td>
<td>93</td>
<td>67</td>
</tr>
<tr>
<td>Right precordial leads</td>
<td>49</td>
<td>89</td>
<td>75</td>
</tr>
<tr>
<td>Right and left precordial leads</td>
<td>52</td>
<td>88</td>
<td>77</td>
</tr>
</tbody>
</table>

Chikamori et al., AJC 3:95

Chikamori et al., AJC 9.94, N = 311
FEMALE, ATYPICAL CHEST PAIN, NORMAL CORONARY ARTERIES

ABNORMAL EXERCISE AND RECOVERY SYSTOLIC BP

- Hypotension
- Abnormal rise in recovery period and/or slow decline in recovery

CHRONOTROPIC INCOMPETENCE* AND ABNORMAL CHRONOTROPIC INDEX** AND PROGNOSIS

Incidence: 15%, 25%
Adds independent information (adjusted risk) to:
- Exercise angina
- Abnormal rest and exercise echo (wall motion score and % ischemic segments)

* ≤ 85% MPHR
** % HR reserve/% metabolic reserve < 0.8
Elhendy et al (Mayo) JACC 2003; 42:823
β-blockers excluded N = 3221
CHRONOTROPIC INCOMPETENCE* DURING EXERCISE ECHO AND PROGNOSIS

Survival free of CAD and MI (%)

<table>
<thead>
<tr>
<th>Age-predicted max HR</th>
<th>Normal – HR ≥ 85%</th>
<th>Normal – HR &lt; 85%</th>
<th>Abnormal – HR ≥ 85%</th>
<th>Abnormal – HR &lt; 85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. at risk</td>
<td>1856</td>
<td>1690</td>
<td>1277</td>
<td>805</td>
</tr>
<tr>
<td>Years</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

Normal – HR ≥ 85% MPHR

Elhendy et al (Mayo) JACC 2003; 42:823

CAUSES OF EXERCISE-RELATED HYPOTENSION

- Aortic stenosis
- Dilated cardiomyopathy
- Severe CAD with poor LV function
- Medications
- Vasovagal syndrome
- Exhaustive effort
- Autonomic insufficiency

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Systolic BP ratio = SBP at 3 min recovery / Peak ex SBP

NI ≤ .90
SBP ≥ .95 predicts extensive hypoperfusion (sens 64%, spec 76%, + PA 74%)

TREADMILL EXERCISE TESTING UCSF FELLOWS 1-26-09 UPDATED 1-21-09
CORRELATES OF ABNORMAL SYSTOLIC BLOOD PRESSURE RATIO (SBPR)

- Extent of CAD (angio)
- Past MI
- Low EF; fall in Ex EF
- CHF
- Extent of hypoperfusion (ischemia + infarction) (scintigraphy)
- Adverse prognosis
- Higher Ex SVR
- Higher Ex NorEP
- Lower work capacity

EXERCISE RESPONSES PREDICTING ADVERSE PROGNOSIS

- Severe ischemic ECG response
- Poor effort tolerance (METs, exercise duration) (true also in ≥ 65 y.o.)
- Chronotropic incompetence
- Hypotension associated with ischemic response
- Abnormal systolic BP ratio (≤ 0.9) (3 min SBP: peak Ex BP)
- Abnormal HR recovery
  - E.g., peak HR: 1 min recovery HR < 20 bpm; peak HR: 2 min recovery HR < 40 bpm
  - criteria not defined
- Duke Treadmill score

IMPAIRED POST EXERCISE HR RECOVERY

- Predicts all cause mortality independent of:
  - Gender
  - Ischemia on ETT or stress echo
  - Duke treadmill score
  - CAD extent and severity
  - Functional capacity
  - β-blockers or rate sparing Ca++ channel blockers
- Incidence: 30%
**Impaired Post Exercise HR Recovery**

- Relationship to:
  - Age
  - HT
  - DM
  - Prior MI
  - Chronotropic incompetence
  - Severe CAD
- Not helpful in predicting presence of any CAD (sensitivity 30%, specificity 76%)
- Mechanism of findings:
  - ? Withdrawal of sympathetic tone
  - ? Impairment in reactivation of parasympathetic nervous system

**Duke Treadmill Score Performance in Pts with Non-Specific ST-T Abnormalities on Resting ECG**

Cardiac death or nonfatal MI

Risk group
- Low
- Intermediate
- High

- Ex time – (5x ST Δ max) – (4x angina index)

Kwok et al JAMA 10.99 N = 906

**Causes of Ischemic-Appearng ECG Abnormalities During Exercise ("False +" Tests*)**

- Hyperventilation (Ds/d vasospasm)
- LVH
- Abnormal ventricular activation
  - WPW
  - LBBB
  - RBBB
- Syndrome X*
- Drugs, electrolytes
  - Hypokalemia
  - Digitalis
- Vasoregulatory abnormalities
- Mitral valve prolapse

*Gold standard is coronary angiography
INDICATIONS FOR STRESS SCINTIGRAPHY

• Exercise ECG uninterpretable for diagnosis of ischemia
  - LBBB - WPW
  - RBBB - LVH
  - Baseline ST-T abnormalities
• Exercise ECG of known low sensitivity
  - Post myocardial infarction
  - Single vessel CAD
• Exercise ECG of possible low specificity
  - Mitral valve prolapse
  - Vasoregulatory abnormalities
  - ? Women
• T wave normalization
EXERCISE RELATED ARRHYTHMIAS - ASSOCIATED CONDITIONS

- Normal cardiopulmonary status
- Coronary artery disease
- Mitral valve prolapse
- Cardiomyopathy
  - Congestive
  - Hypertrophic
- Aortic valvular stenosis
- Long QT interval syndromes
  - Congenital
  - Acquired
- Digitalis administration

EXERCISE-INDUCED VENTRICULAR ARRHYTHMIAS AND SURVIVAL

<table>
<thead>
<tr>
<th>Follow-up (mo)</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>95</td>
</tr>
<tr>
<td>24</td>
<td>90</td>
</tr>
<tr>
<td>36</td>
<td>85</td>
</tr>
<tr>
<td>48</td>
<td>80</td>
</tr>
</tbody>
</table>

Eckart et al. AIM 2008; 149:451
PREDICTIVE ACCURACY FOR CAD OF INTRAVENTRICULAR CONDUCTION DELAYS AND SUPRAVENTRICULAR ARRHYTHMIAS IN AN ASYMPTOMATIC POPULATION

<table>
<thead>
<tr>
<th>Condition</th>
<th>Prevalence</th>
<th>Predictive accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBBB</td>
<td>0.2%</td>
<td>20%</td>
</tr>
<tr>
<td>LBBB</td>
<td>0.1%</td>
<td>24%</td>
</tr>
<tr>
<td>AF, other</td>
<td>0.1%</td>
<td>14%</td>
</tr>
<tr>
<td>SV arrhythmias</td>
<td>0.1%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Froelicher, et al, AJC 1.77  N = 298

EXERCISE-INDUCED SUPRAVENTRICULAR ARRHYTHMIAS INNormals

• Prevalence 6%
• Relation to age (men)
• 98% are paroxysmal
• 16% are > 10 beats
• Symptoms in 4%
• Most (44%) episodes occur at peak effort

Mauer et al, Baltimore Aging Study, AJC 4.95
843 men, 540 women; FU mean 6 yr

20TREADMILL EXERCISE TESTING UCSF FELLOWS 1-26-09 UPDATED 1-21-09
EXERCISE INDUCED ATRIAL ARRHYTHMIAS

Survival free of MACE (%)

Years

P = 0.1

None
AF/flutter
Atrial ectopy
SVT

Survival (%)

Years

P = 0.429

None
AF/flutter
Atrial ectopy
SVT

Cardiac survival (%)

0 1 2 3 4 5

0 1 2 3 4 5

Bunch et al. JACC 2004; 43:1236
Mayo Clinic N = 5375 CAD known/suspected

Bunch et al. JACC 2004; 43:1236
Mayo Clinic N = 5375 CAD known/suspected
BUNDLE BRANCH BLOCK IN TREADMILL TESTING

• Predictive accuracy depends on prevalence of coronary disease in population studied. PA is about 20% in asx subjects
• Predictive accuracy of intermittent, rate-dependent and newly acquired BBB is unknown
• Criteria for ischemia apply in lateral leads in RBBB, not in LBBB, although sensitivity is reduced due to the secondary ST-T abnormalities
VAGAL BRADYCARDIA DURING TREADMILL EXERCISE

- Uncommon
- Usually young, healthy, active individuals
- Abrupt bradycardia-hypotension at peak exercise or during recovery
  - Often without warning
  - May be associated with syncope
- Rapid recovery without sequelae
- May be related to stimulation of left ventricular mechanoreceptors
- May be reproducible
- Does not indicate sinus node dysfunction

EXERCISE-INDUCED AV BLOCK

- Occurs in < 1% of all exercise tests
- Usually intra-His (QRS normal) or infra-His (BBB at rest)
- High (> 90%) rate of progression to chronic AV block
- Cardiac pacing indicated
56 y.o. male, post-aortocoronary bypass surgery 3 yr prior, developed ill feeling with effort

62 y.o. male - trifascicle disease