Section 09: Interpretation of Clinical GXT Data

ACSM Guidelines: Chapter 6

HPHE 4450
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Outline

• Heart rate response
• Blood pressure response
• ECG abnormalities
• Gas exchange (VO₂ max), Functional Capacity
• Signs and Symptoms
• Diagnostic value
• Prognostic interpretations
**Interpretation Overview**

- The objective of exercise testing it to evaluate quantitatively and accurately the following variables:
  - Hemodynamic Response
    - Heart Rate
    - Blood Pressure
  - ECG Waveforms
    - Especially ST-segment displacement
    - Supraventricular and ventricular dysrhythmias
  - Gas Exchange/Ventilatory Responses

**Heart Rate Exercise Response**

- **Normal:**
  - Relatively linear increase in response to progressive exercise corresponding to 10 ± 2 beats per MET

- **Abnormal (chronotropic incompetence):**
  - A peak exercise HR that is > 2 SD (~20 b/min) below age-predicted maximal HR.
  - Or, an inability to achieve > 85% of the age-predicted maximal HR for subjects who are limited by volitional fatigue and are not taking beta blockers
  - A chronotropic index < 0.8
    - \( CI = \frac{\text{Meas. HRpeak-HRrest}}{(220-\text{age}-HRrest)} x 100 \)
Heart Rate Recovery Response

- Normal:
  - A decrease from peak HR of at least 13 beats/min at 1 min recovery (walking in recovery)
  - Or, a decrease from peak HR of at least 23 beats/min at 2 min recovery (supine position in recovery)

- Abnormal:
  - A decrease from peak HR ≤ 12 beats/min at 1 min recovery (walking in recovery)
  - Or, a decrease from peak HR ≤ 22 beats/min at 2 min recovery (supine position in recovery)

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Heart Rate Response

![Graph showing heart rate response to submaximal, maximal effort, and supine recovery](image)

**FIGURE 6-1.** The hemodynamic responses of more than 700 healthy men to maximal treadmill exercise. Bands represent 90% of the population, with 10% having values exceeding the upper limit and 10% having lower values. (Reprinted with permission from Wolfarth RA, Froelicher VF, Fischer I, et al. The response of healthy men to treadmill exercise. Circulation 1977;55:153-157.)
**Blood Pressure Response**

- **Normal Response:**
  - During exercise:
    - Progressive increase in SBP with increasing exercise intensity
      - Typically $10 \pm 2$ mmHg per MET
    - No change or slight decrease in DBP with increasing exercise intensity
    - Widening of the pulse pressure (SBP-DBP)
  - Post-Exercise
    - A progressive decline in SBP
    - During passive recovery, SBP may decrease abruptly because of peripheral pooling
    - DBP may drop during post-exercise period
    - SBP may remain below pretest resting values for several hours after test.

- **Abnormal Response:**
  - A drop in SBP (> 10 mmHg) despite an increase in workload.
  - A failure of SBP to increase with increased workload
    - Exercise induced decreases in SBP (exertional hypotension) may occur in patients with CAD, valvular disease, cardiomyopathies, and serious dysrhythmias.
      - Correlations with myocardial ischemia, left ventricular dysfunction and an increased risk of subsequent cardiac events.
  - SBP > 250 mmHg
  - Maximal exercise SBP < 140 mmHg suggests poor prognosis
  - DBP > 115 mmHg
Blood Pressure Response

• Other notes:
  – Patients on “drugs” can have an attenuated response
  – Men typically have higher SBP during maximal treadmill testing (< 70 yrs)
  – The rate-pressure product (RPP) (SBP x HR) is an indicator of myocardial oxygen demand. Signs and symptoms of ischemia generally occur at a reproducible RPP. (See next slide)

Rate-Pressure Product (RPP)

• Rate pressure product (RPP) or double product (DP)
  – RPP = HR x SBP x 10²
    • In other words: RPP = (HR x SBP) / 100
  – Reflects myocardial oxygen demand
  – Useful in testing and training individuals with cardiovascular disease (anginal prediction)
    • Often times, a cardiac patient will exhibit angina at a specific, replicable RPP.
      – Therefore, this information can be used for exercise prescription (i.e. exercise at an intensity below the RPP that the angina occurred at)
**Blood Pressure Response**

**TABLE 6-1. Mean (±SD) Peak SBP and DBP (mm Hg) During Maximal Treadmill Exercise**

<table>
<thead>
<tr>
<th>Age</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBP</td>
<td>DBP</td>
</tr>
<tr>
<td>18–29</td>
<td>182 ± 22</td>
<td>69 ± 13</td>
</tr>
<tr>
<td>30–39</td>
<td>182 ± 20</td>
<td>76 ± 12</td>
</tr>
<tr>
<td>40–49</td>
<td>186 ± 22</td>
<td>78 ± 12</td>
</tr>
<tr>
<td>50–59</td>
<td>192 ± 22</td>
<td>82 ± 12</td>
</tr>
<tr>
<td>60–69</td>
<td>195 ± 23</td>
<td>83 ± 12</td>
</tr>
<tr>
<td>70–79</td>
<td>191 ± 27</td>
<td>81 ± 13</td>
</tr>
</tbody>
</table>


**Blood Pressure Response**

**FIGURE 6-1.** The hemodynamic responses of more than 700 healthy men to maximal treadmill exercise. Bands represent 80% of the population, with 10% having values exceeding the upper limit and 10% having lower values. (Reprinted with permission from Wolthius RA, Froelicher VF, Fischer J, et al. The response of healthy men to treadmill exercise. Circulation 1977;55:153–157.)
Electrocardiograph Waveforms

- ECG represents the electrical activity of the heart NOT contraction of the heart
- Can be used to diagnose myocardial ischemia
- Review the electrical pathways of the heart
- Review the P-QRS-T waveform
- Normal responses to exercise
- Use Appendix C (ACSM Guidelines)
Electrocardiograph Waveforms

• ST-Segment Displacement
  – ST-segment changes are widely accepted criteria for myocardial ischemia and injury.
  – Exercise induced myocardial ischemia may be manifested by three different types of ST-segment changes on the ECG

Electrocardiograph Waveforms

• ST-segment depression
  – Abnormal:
    • ≥ 1 mm of horizontal or downloping ST depression 60-80 msec beyond the J point

• ST-segment elevation
  – Abnormal:
    • ST elevation in leads displaying a previous Q-wave MI almost always reflects an aneurysm or wall motion abnormality
    • In the absence of significant Q-waves, exercise induced ST elevation often is associated with a fixed high-grade coronary stenosis.
      – Significant Q-Wave: > 0.04 s and/or >25% of R-Wave amplitude (except in Lead III or V1)
When horizontal or downsloping ST segment depression is present, the likelihood of cardiac ischemia is:

- 0.5 mm depression => possible ischemia (odds ~ 50%)
- 1 mm depression => probable ischemia (odds ~ 75%)
- 1.5 - 2 mm depression => almost certain ischemia (odds ~ 90%)
Electrocardiograph Waveforms

- Adjustment of the ST segment relative to the HR may provide additional diagnostic information.
  - The ST/HR index is the ratio of the maximal ST-segment change (measured in mV) to the maximal change in HR from rest to peak exercise (measured in beats·min⁻¹).
  - An ST/HR index of ≥1.6 is defined as abnormal. The ST/HR slope reflects the maximal slope relating the amount of the ST-segment depression (measured in mV) to HR (measured in beats·min⁻¹) during exercise. An ST/HR slope of >2.4 mV·beats⁻¹·min⁻¹ is defined as abnormal.

Electrocardiograph Waveforms

- Arrhythmias
  - Supraventricular Dysrhythmias
    - Isolated atrial ectopic beats or short runs of SVT commonly occur during exercise testing and do not appear to have any diagnostic or prognostic significance for CVD
      - Premature Atrial Contractions
      - Atrial flutter
      - Atrial fibrillation
      - Supraventricular Tachycardia
Electrocardiograph Waveforms

- Atrial Flutter
  - Atrial Rate 250 - 350 bpm

- Atrial Fibrillation
  - Atrial Rate 400 - 500 bpm

Electrocardiograph Waveforms

- Arrhythmias
  - Ventricular Dysrhythmias
    - Premature Ventricular Contracts (PVC)
      - 30-40% of healthy subjects
      - 50-60% of CAD patients
    - Ventricular Tachycardia
    - Ventricular Fibrillation
Electrocardiograph Waveforms

- **Ventricular tachycardia**
- **Ventricular Fibrillation (V Fib)**: "sawtooth"

Anginal Symptoms

- A rating of 3 (moderately severe) generally should be used as an endpoint for exercise testing.
**Functional Capacity / VO$_{2max}$**

- Three common approaches to predicting CRF from exercise tests:
  - Multiplication of total test time
  - MET costs associated with the different stages of the exercise test.

**Functional Capacity / VO$_{2max}$**

- VO$_{2max}$ from Total Test Time
  - Bruce Protocol
    - Men: VO$_{2max}$ (mL/kg/min) = 2.94 x Time (min) + 7.65
    - Women: VO$_{2max}$ (mL/kg/min) = 2.94 x Time (min) + 3.74
    - Young Men: VO$_{2max}$ (mL/kg/min) = 3.62 x Time (min) + 3.91
  - Balke Protocol
    - VO$_{2max}$ (mL/kg/min) = 1.51 x Time (min) + 11.12
**Functional Capacity / VO$_{2\text{max}}$**

**BOX 8.3 Prediction of VO$_{2\text{max}}$ from Treadmill Test Time**

**BRUCE PROTOCOL**
Healthy persons (3)

\[
\text{VO}_{2\text{max}} \text{ (mL \cdot kg}^{-1} \cdot \text{min}^{-1}) = 6.7 - 2.82 (\text{men} = 1, \text{women} = 2) + 0.056 \text{ (time in sec)}
\]

Healthy men and women (n = 296)

\[
\text{VO}_{2\text{max}} \text{ (mL \cdot kg}^{-1} \cdot \text{min}^{-1}) = 3.814 \text{ (time in min)} = 3.938 \pm 4.68 \quad (r = 0.87)
\]

(Updated data—Ball State University [BSU] Adult Physical Fitness Program)

**BSU-BRUCE RAMP PROTOCOL (6)**

Men and women (n = 392)

\[
\text{VO}_{2\text{max}} \text{ (mL \cdot kg}^{-1} \cdot \text{min}^{-1}) = 3.9 \text{ (time in min)} = 7.0 \pm 3.4 \quad (r = 0.93)
\]

**BALKE PROTOCOL**

Women (n = 43) = 3.0 mph protocol with 2.5%/3 min (11)

\[
\text{VO}_{2\text{max}} \text{ (mL \cdot kg}^{-1} \cdot \text{min}^{-1}) = 0.023 \text{ (time in sec)} + 5.2 \pm 2.7 \quad (r = 0.94)
\]

Men (n = 51) = 3.3 mph protocol (10)

\[
\text{VO}_{2\text{max}} \text{ (mL \cdot kg}^{-1} \cdot \text{min}^{-1}) = 1.444 \text{ (time in min)} + 14.99 \pm 0.025 \quad (r = 0.92)
\]

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**Functional Capacity / VO$_{2\text{max}}$**

- MET Costs Associated with Stage

**TABLE 9-6 METABOLIC EQUIVALENTS PER MINUTE OF THE BRUCE TREADMILL PROTOCOL**

<table>
<thead>
<tr>
<th>MIN</th>
<th>METs</th>
<th>MIN</th>
<th>METs</th>
<th>MIN</th>
<th>METs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.1</td>
<td>6</td>
<td>7.4</td>
<td>11</td>
<td>11.6</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
<td>7</td>
<td>8.3</td>
<td>12</td>
<td>12.5</td>
</tr>
<tr>
<td>3</td>
<td>4.9</td>
<td>8</td>
<td>9.1</td>
<td>13</td>
<td>13.3</td>
</tr>
<tr>
<td>4</td>
<td>5.7</td>
<td>9</td>
<td>10</td>
<td>14</td>
<td>14.1</td>
</tr>
<tr>
<td>5</td>
<td>6.6</td>
<td>10</td>
<td>10.7</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

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**Functional Capacity / VO\textsubscript{2max}**

**TABLE 8.3. BRUCE TREADMILL PROTOCOL (3)**

<table>
<thead>
<tr>
<th>STAGE</th>
<th>TIME (min:sec)</th>
<th>SPEED (mph)</th>
<th>GRADE (%)</th>
<th>METS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:00</td>
<td>1.7</td>
<td>10.0</td>
<td>4.7</td>
</tr>
<tr>
<td>2</td>
<td>3:00</td>
<td>2.5</td>
<td>12.0</td>
<td>7.0</td>
</tr>
<tr>
<td>3</td>
<td>6:00</td>
<td>3.4</td>
<td>14.0</td>
<td>10.1</td>
</tr>
<tr>
<td>4</td>
<td>9:00</td>
<td>4.2</td>
<td>18.0</td>
<td>12.9</td>
</tr>
<tr>
<td>5</td>
<td>12:00</td>
<td>5.0</td>
<td>18.0</td>
<td>15.0</td>
</tr>
<tr>
<td>6</td>
<td>15:00</td>
<td>5.5</td>
<td>20.0</td>
<td>16.9</td>
</tr>
<tr>
<td>7</td>
<td>18:00</td>
<td>6.0</td>
<td>22.0</td>
<td></td>
</tr>
</tbody>
</table>

Note: a modification for less fit clients is to add one or two preliminary stages:

<table>
<thead>
<tr>
<th>STAGE</th>
<th>TIME (min:sec)</th>
<th>SPEED (mph)</th>
<th>GRADE (%)</th>
<th>METS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0:00</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.5</td>
<td>3:00</td>
<td>1.7</td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>

See Figure 8.3 for estimated metabolic equivalent levels.


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**Functional Capacity / VO\textsubscript{2max}**

- Average values for VO\textsubscript{2max} expressed as METs, expected in healthy sedentary men and women, can be predicted from the following regression equations:
  - Men: \((57.8 - (0.445 \times \text{age}))/3.5\)
  - Women: \(((41.2 - (0.343 \times \text{age}))/3.5\)
**Diagnostic Value of GXT**

**BOX 6.2 Sensitivity, Specificity, and Predictive Value of Diagnostic Graded Exercise Testing**

- **Sensitivity** = TP/(TP + FN) = the percentage of patients with CAD who have a positive test
- **Specificity** = TN/(TN + FP) = the percentage of patients without CAD who have a negative test
- **Predictive Value (positive test)** = TP/(TP + FP) = the percentage of patients with a positive test result who have CAD
- **Predictive Value (negative test)** = TN/(TN + FN) = the percentage of patients with a negative test who do not have CAD

Abbreviations: TP, true positive (positive exercise test and coronary artery disease [CAD]); FP, false positive (positive exercise test and no CAD); TN, true negative (negative exercise test and no CAD); FN, false negative (negative exercise test and CAD).

**Diagnostic Value of GXT**

**BOX 6.3 Causes of False-Negative Test Results**

- Failure to reach an ischemic threshold
- Monitoring an insufficient number of leads to detect ECG changes
- Failure to recognize non-ECG signs and symptoms that may be associated with underlying CVD (e.g., exertional hypotension)
- Angiographically significant CVD compensated by collateral circulation
- Musculoskeletal limitations to exercise preceding cardiac abnormalities
- Technical or observer error

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## Diagnostic Value of GXT

**BOX 6.4 Causes of Abnormal ST Changes in the Absence of Obstructive Coronary Artery Disease**

- Resting repolarization abnormalities (e.g., left bundle-branch block)
- Cardiac hypertrophy
- Accelerated conduction defects (e.g., Wolff-Parkinson-White syndrome)
- Digitalis
- Nonischemic cardiomyopathy
- Hypokalemia
- Vasoregulatory abnormalities
- Mitral valve prolapse
- Pericardial disorders
- Technical or observer error
- Coronary spasm in the absence of significant coronary artery disease
- Anemia
- Female sex

*Selected variables simply may be associated with rather than be causes of abnormal test results.

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## Prognostic Application

**ST-Segment deviation during exercise**

- **Ischemia-reading line**
  - None
  - Nonlimiting
  - Exercise-limiting

- **Angina during exercise**
  - 0 mm
  - 1 mm
  - 2 mm
  - 3 mm
  - 4 mm

- **Prognosis**
  - 5-year survival
  - Average annual mortality
  - Exercise METs

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