Box 5.4 Indications for Terminating a Symptom-Limited Maximal Exercise Test

Absolute Indications

- ST elevation (>1.0 mm) in leads without preexisting Q waves because of prior MI (other than aVR, aVL, or V_1)
- Drop in systolic blood pressure of >10 mm Hg, despite an increase in workload, when accompanied by other evidence of ischemia
- Moderate-to-severe angina
- Central nervous system symptoms (*e.g.*, ataxia, dizziness, or near syncope)
- Signs of poor perfusion (cyanosis or pallor)
- Sustained ventricular tachycardia or other arrhythmia, including second- or third-degree atrioventricular block, that interferes with normal maintenance of cardiac output during exercise
- Technical difficulties monitoring the ECG or systolic blood pressure
- The subject's request to stop

Relative Indications

- Marked ST displacement (horizontal or downsloping of >2 mm, measured 60 to 80 ms after the J point in a patient with suspected ischemia)
- Drop in systolic blood pressure >10 mm Hg (persistently below baseline) despite an increase in workload, *in the absence* of other evidence of ischemia
- Increasing chest pain
- Fatigue, shortness of breath, wheezing, leg cramps, or claudication
- Arrhythmias other than sustained ventricular tachycardia, including multifocal ectopy, ventricular triplets, supraventricular tachycardia, and bradyarrhythmias that have the potential to become more complex or to interfere with hemodynamic stability
- Exaggerated hypertensive response (systolic blood pressure >250 mm Hg or diastolic blood pressure >115 mm Hg)
- Development of bundle-branch block that cannot be distinguished from ventricular tachycardia
- SpO_2 ≤80% (3)

ECG, electrocardiogram; MI, myocardial infarction; SpO_2, percent saturation of arterial oxygen.

Adapted with permission from (21).

Conducting the Clinical Exercise Test (cont.)

- Postexercise and safety
  - Each laboratory should develop standardized procedures for the postexercise recovery period (active vs. inactive and monitoring duration) with the laboratory's medical director that considers the indication for the exercise test and the patient's status during the test
  - Although untoward events do occur, clinical exercise testing is generally safe when performed by appropriately trained clinicians

Interpreting the Clinical Exercise Test

- Multiple factors should be considered during the interpretation of exercise test data including patient symptoms, ECG responses, exercise capacity, hemodynamic responses, and the combination of multiple responses, as reflected by exercise test scores such as the Duke Treadmill Score

Interpreting the Clinical Exercise Test (Cont.)

- Heart Rate Responses
  - The normal HR response to incremental exercise is to increase with increasing workloads at a rate of ~10 beats · min^{-1} per 1 MET
  - HRmax decreases with age and is attenuated in patients on β-adrenergic blocking agents. Several equations have been published to predict HRmax in individuals who are not taking a β-adrenergic blocking agent
  - All estimates have large interindividual variability with standard deviations of 10 beats or more

Interpreting the Clinical Exercise Test (Cont.)

- Heart Rate Responses (Cont.)
  - Among patients referred for testing secondary to IHD and in the absence of β-adrenergic blocking agents, failure to achieve an age-predicted HRmax $\geq$85% in the presence of maximal effort is an indicator of chronotropic incompetence and is independently associated with increased risk of morbidity and mortality
  - The rate of decline in HR following exercise provides independent information related to prognosis

Interpreting the Clinical Exercise Test (Cont.)

- Blood Pressure Response
  - The normal systolic blood pressure (SBP) response to exercise is to increase with increasing workloads at a rate of ~10 mm Hg per 1 MET. There is normally no change or a slight decrease in diastolic blood pressure (DBP) during an exercise test
    - Specific SBP responses:
      - Hypertensive response
      - Hypotensive Response
      - Blunted Response
      - Postexercise response

Interpreting the Clinical Exercise Test (Cont.)

- Rate Pressure Product
  - Rate-pressure product (also known as *double product*) is calculated by multiplying the values for HR and SBP that occur at the same time during rest or exercise. Rate-pressure product is a surrogate for myocardial oxygen uptake
    - There is a linear relationship between myocardial oxygen uptake and both coronary blood flow and exercise intensity
    - The normal range for peak rate-pressure product is 25,000–40,000 mm Hg · beats · min $^{-1}$

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- The normal response of the ECG during exercise includes the following:
- P-wave: increased magnitude among inferior leads
- PR segment: shortens and slopes downward among inferior leads
- QRS: Duration decreases, septal Q-waves increase among lateral leads, R waves decrease, and S waves increase among inferior leads.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- The normal response of the ECG during exercise includes the following (Cont.):
  - J point (J junction): depresses below isoelectric line with upsloping ST segments that reach the isoelectric line within 80 ms
  - T-wave: decreases amplitude in early exercise, returns to preexercise amplitude at higher exercise intensities, and may exceed preexercise amplitude in recovery
  - QT interval: Absolute QT interval decreases. The QT interval corrected for HR increases with early exercise and then decreases at higher HRs.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- The normal response of the ECG during exercise includes the following (Cont.):
  - ST-segment changes (*i.e.*, depression and elevation) are widely accepted criteria for myocardial ischemia and injury. The interpretation of ST segments may be affected by the resting ECG configuration and the presence of digitalis therapy

Box 5.5 Considerations That May Necessitate Adjunctive Imaging When the Indication Is the Assessment of Ischemic Heart Disease (21)

- Resting ST-segment depression >1.0 mm
- Ventricular paced rhythm
- Left ventricular hypertrophy with repolarization abnormalities
- Left bundle-branch block
- Leads V1 through V3 will not be interpretable with right bundle-branch block.
- Wolff-Parkinson-White
- Digitalis therapy

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- Abnormal response of the ST segment during exercise includes the following:
  - To be clinically meaningful, ST-segment depression or elevation should be present in at least three consecutive cardiac cycles within the same lead. The level of the ST segment should be compared relative to the end of the PR segment. Automated computer-averaged complexes should be visually confirmed.
  - Horizontal or downsloping ST-segment depression $\geq$ 1 mm (0.1 mV) at 80 ms after the J point is a strong indicator of myocardial ischemia.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- Abnormal response of the ST segment during exercise includes the following (Cont.):
  - Clinically significant ST-segment depression that occurs during postexercise recovery is an indicator of myocardial ischemia.
  - ST-segment depression at a low workload or low rate-pressure product is associated with worse prognosis and increased likelihood for multivessel disease.
  - When ST-segment depression is present in the upright resting ECG, only additional ST-segment depression during exercise is considered for ischemia.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- Abnormal response of the ST segment during exercise includes the following (Cont.):
  - When ST-segment elevation is present in the upright resting ECG, only ST-segment depression below the isoelectric line during exercise is considered for ischemia.
  - Upsloping ST-segment depression $\geq$ 2 mm (0.2 mV) at 80 ms after the J point may represent myocardial ischemia, especially in the presence of angina. However, this response has a low positive predictive value; it is often categorized as equivocal.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- Abnormal response of the ST segment during exercise includes the following (Cont.):
  - Among patients after myocardial infarction (MI), exercise-induced ST-segment elevation (> 1 mm or > 0.1 mV for 60 ms) in leads with Q waves is an abnormal response and may represent reversible ischemia or wall motion abnormalities.
  - Among patients without prior MI, exercise-induced ST-segment elevation most often represents transient combined endocardial and subepicardial ischemia but may also be due to acute coronary spasm.

Interpreting the Clinical Exercise Test (Cont.)

- Electrocardiogram
- Abnormal response of the ST segment during exercise includes the following (Cont.):
  - Repolarization changes (ST-segment depression or T-wave inversion) that normalize with exercise may represent exercise-induced myocardial ischemia but is considered a normal response in young subjects with early repolarization on the resting ECG.
- In general, dysrhythmias that increase in frequency or complexity with progressive exercise intensity and are associated with ischemia or with hemodynamic instability are more likely to cause a poor outcome than isolated dysrhythmias

Interpreting the Clinical Exercise Test (Cont.)

- Symptoms
  - Symptoms that are consistent with myocardial ischemia (*e.g.*, angina, dyspnea) or hemodynamic instability (*e.g.*, light-headedness) should be noted and correlated with ECG, HR, and BP abnormalities (when present).

Interpreting the Clinical Exercise Test (Cont.)

- Exercise Capacity
  - Evaluating exercise capacity is an important aspect of exercise testing
    - A high exercise capacity is indicative of a high peak Q and therefore suggests the absence of serious limitations of left ventricular function
    - A significant issue relative to exercise capacity is the imprecision of estimating exercise capacity from exercise time or peak workload.
      - The standard error in estimating exercise capacity from various published prediction equations is at least ± 1MET