1 Introduction

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Introduction

The stress (exercise) ECG test serves as an important and valuable assessment tool that provides diagnostic and prognostic information in the clinical evaluation and management of patients with known or suspected cardiovascular disease, particularly coronary artery disease (CAD).

Various protocols for exercise stress testing have been in in existence for several decades. Early protocols for exercise testing, such as Master's two-step test, lacked sufficient sensitivity for clinical use. Currently in the United States, exercise electrocardiography is most commonly performed using a motor-driven treadmill. In Europe, where bicycling is more habitual, exercise stress testing is more commonly performed using a bicycle ergometer.

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Several multistage exercise ECG testing protocols have been developed for use with either a motorized treadmill (the Bruce protocol or its modification are the most widely used in the United States) or cycle ergometer (see Chapter 5).

For those unable to perform sufficient physical exertion to adequately complete an exercise ECG test, or when specific clinical conditions exist, pharmacological stress testing with vasodilators or dobutamine is indicated (see Chapter 8). Among patients with resting ECG abnormalities expected to affect repolarization that potentially lead to situations where the ECG response to exercise would be considered non-diagnostic or falsely positive, imaging with echocardiography or myocardial perfusion imaging (MPI) is indicated. Stress echocardiography is also indicated in specific situations in the assessment of valvular heart disease (see Chapter 7). For selected patients with indwelling permanent cardiac pacemakers, the gradual increase of the atrial paced rate can provide an adequate assessment for myocardial ischemia when combined with a myocardial imaging technique.

The exercise ECG test is used primarily to assess the etiology of chest pain and for detection of CAD. In addition, the exercise ECG test can provide important information about functional capacity (prognosis) and the efficacy of medical and surgical therapy for patients with CAD. Furthermore, an exercise ECG test can be quite useful in assessing the ability of an individual to participate in an exercise program or sport (see Chapters 18 and 19), in the evaluation exercise-related symptoms, or for assessment of chronotropic competence or exercise-related arrhythmias.

Myocardial imaging should be performed in combination with the exercise ECG test when false positive or false negative exercise ECG results are anticipated or found and when the exercise ECG test result is equivocal. Due to the infrequent occurrence of ST-segments shifts with pharmacological stress agents, myocardial imaging is required when pharmacological stress testing is performed (see Chapter 11).

Pathophysiologic Considerations

The exercise stress ECG test has two major purposes:

1) To determine the capability of the coronary circulation to increase oxygen delivery to the myocardium in response to an increased demand. During physical exertion, myocardial oxygen demand is increased by the increase in systolic blood pressure (SBP), contractile state of the heart, and increase of heart rate (HR).
2) To assess the exercise capacity. The major factor determining the exercise capacity is the ability to increase the cardiac output; the product of stroke volume (SV) and HR. In normal individuals, cardiac output (Q) typically increases by a factor of four to sixfold from the resting condition to peak exercise. During moderate to high-intensity exercise, the further increase in Q is primarily attributable to an increase in HR, as SV generally reaches a plateau at 50–60% of maximal oxygen uptake.

As it is known that the heart already extracts approximately 70% of the oxygen from each unit of blood perfusing the myocardium at rest, oxygen delivery to the myocardium cannot be increased significantly by increasing oxygen extraction. For practical purposes, myocardial metabolism is entirely aerobic, thus coronary blood flow must increase in order to augment the myocardial oxygen supply. In healthy individuals, coronary blood flow is documented to increase in proportion to increased myocardial demand for oxygen.

In response to stress in patients with significant CAD, coronary blood flow fails to adequately increase to meet the increased demand of the myocardium for oxygen, leading to myocardial ischemia. Myocardial ischemia may manifest in a variety of ways during a stress test including anginal pain, ST-segment and/or T-wave changes, ventricular dysfunction, various cardiac arrhythmias, or any combination of the preceding.

Physical exercise leads to an increment of myocardial oxygen consumption via the increased HR, intra-myocardial tension, and contractility. With progressive exercise, coronary blood flow can increase as much as four to sixfold above the basal value. Acceleration of the HR is associated with a linear increment of myocardial oxygen consumption; thus the HR response to an exercise bout provides a useful parameter of myocardial oxygen requirements. By measuring the (systolic) BP during exercise, the product of the HR and BP ("double product" or "rate-pressure product") can be derived, which can serve as a practical index of myocardial oxygen uptake.

Preparations and Precautions

As shall be discussed in further detail in Chapter 2, the exercise ECG test requires certain preparations and due consideration of precautions in order to perform the test appropriately and safely. The nature and purpose of the test should be explained in appropriate detail to the patient. All stress tests must be ordered by a licensed independent practitioner. Upon receipt and acceptance of the order by the stress laboratory, the stress test is scheduled as an elective procedure for outpatients as well as for inpatients.

Patients who are to undergo a stress test should be given the following instructions:

- Report for the test either after an overnight fast or three hours following a light meal.
- Routine medications may be taken with small amounts of water.
- Dress in comfortable clothing and wear comfortable walking shoes or sneakers.

Before a patient is to perform a stress test, the following procedures must be performed:

- A witnessed informed consent document must be obtained by the professional performing/supervising the stress test. This is an important medico-legal requirement (see Chapter 21). Translation services should be provided for non–English-speaking patients.

- A brief history and physical examination should be performed to determine whether the patient is suitable for the proposed test.
- The indication(s) for the test along with any potential contraindication(s) which may exist (see Chapters 3 and 4) should be carefully considered
- Determine whether the patient is taking any medication (e.g. beta-blockers, organic nitrates, calcium channel blockers, digitalis preparation, etc.) that may influence the result(s) of the stress test (see Chapter 15).

The following precautions should be observed prior to initiation of the stress test:

- Maintain the exercise stress laboratory at a comfortable temperature, generally between 68° and 72 °F, with 40–60% humidity.
- Instruct the patient in full regarding the stress test procedure.
- Have the patient rest comfortably in the supine position for a period of 5–10 minutes before the test is performed.
- A standard 12-lead ECG (supine and standing) should be obtained to determine the presence of any acute cardiac events (ECG changes) or any possible contraindications. The modified lead placement with the Mason-Likar ("torso") system used during stress may alter the inferior lead complexes to either mimic or hide previous Q waves.
- The stress test should be supervised by a licensed, qualified healthcare professional fully familiar with all aspects of the procedure, including use of the equipment, test interpretation, and recognition of potential complications that may arise. If a non-physician (nurse, nurse practitioner, physician assistant, exercise physiologist) is designated to supervise the stress test, a physician skilled in stress testing should be immediately available in the vicinity for consultation and assistance should such a situation arise.

During the test, the procedure should be halted immediately if either of the following occurs:

- The patient requests that the test stop.
- The patient develops significant symptoms (e.g. chest pain, dizziness, dyspnea, etc.), hypotension, cyanosis, bradycardia, or other serious cardiac arrhythmias and/or marked ST-segment changes.

Anyone supervising a stress test must be prepared for emergency situations:

- Although a rare occurrence, all necessary equipment for cardiac resuscitation must be immediately available in the stress laboratory.
- Treating patients immediately for significant symptoms, cardiac arrhythmias, and any other untoward complications.

The staff supervising the stress test must inspect all emergency equipment on a daily basis to ensure that any serious complication can be managed immediately, and all qualified healthcare personnel working in the stress laboratory must be capable of handling any cardiopulmonary emergencies (see Chapter 13).

Methodology

Methods of Stress

- *Exercise (stress) ECG test.* A motor-driven treadmill is the most commonly used device in the United States. Can also be accomplished using a cycle ergometer (more popular in Europe) or an arm ergometer (not commonly utilized).
- *Pharmacological stress testing.* Vasodilators (dipyridamole, adenosine, and regadenoson) or a catecholamine (dobutamine) can be used for those unable to perform an exercise stress test or in specific clinical situations (see Chapters 8 and 11).
- *Artificial pacing.* In selected patients with an indwelling cardiac pacemaker, the device can be used increase HR and assess for inducible myocardial ischemia. In rare instances today, a swallowed pill electrode can be used to pace the heart.

Protocols for the Treadmill Exercise ECG Test

As will be discussed further in Chapter 5, a number of multistage exercise protocols have been devised. In clinical practice, the Bruce protocol is employed most widely. Among certain subsets of patients or for specific clinical situations, an exercise protocol other than the Bruce protocol may be the more appropriate choice.

Planning the Ideal Exercise ECG Stress Test

- The initial workload should be within an individual's anticipated physical working capacity. Workloads should be increased gradually, not abruptly, and should be maintained for a sufficient length of time (generally three minutes) to attain a near physiological study state.
- Continuously monitoring HR, ST-segments, and cardiac rhythm during exercise is essential as is measuring BP during each stage. In addition, it is important to monitor the patient for signs and symptoms (chest pain, dyspnea, dizziness, extreme fatigue, perceived exertion) which may develop during an exercise bout as these may presage development of significant ECG changes or hemodynamic issues. As some abnormal responses occur after exercise, monitoring should continue for six to eight minutes in the post-exercise recovery period, or longer, if the patient is symptomatic or if BP, HR, and/or ST-segments have not returned to near-baseline values.
- An exercise ECG test is most often designed to be "symptom-limited;" most tests should be terminated because of fatigue, significant symptoms, and/or ECG changes rather than attainment of a particular HR goal.
- The exercise ECG test should be terminated immediately if significantly abnormal symptoms, marked ST-segment changes, serious arrhythmias, or significant shifts in blood pressure are found.

Choosing the Exercise ECG Protocol

As stated above, a variety of multistage protocols exist; the Bruce protocol is most widely used.

- With some exercise ECG protocols, workload is increased by changing speed alone while maintaining a fixed grade (incline or elevation).
- In the Bruce protocol, the workload is changed incrementally by increasing both the speed and grade of the treadmill.
- For the progressive increment of workload, three-minute intervals are preferable so that steady-state BP and HR responses can be achieved.
- A submaximal ("low-level") exercise ECG test protocol is recommended by some cardiologists in the setting of a stable patient following a recent myocardial infarction (MI) or acute coronary syndrome without full revascularization.

Metabolic equivalents (METs), multiples of the basal metabolic rate (1 MET is defined as ≈3.5 mlO_2 per kilogram of body weight per minute [ml/kg/min]), are commonly used to express the workload in various stages of the exercise ECG testing protocols.

- In the majority of patients with CAD, a workload of 8 METs is often sufficient for evaluation of angina pectoris.
- Healthy sedentary subjects are seldom able to exercise beyond a workload of 10–11 METs.
- Physically active individuals may be capable of achieving workloads in excess of 16 METs.

When correlating cardiac functional capacity with exercise workload expressed in METs, the following relationships are generally observed:

- Functional class III patients often become symptomatic at a workload of 3–4 METs.
- Functional class II patients often are limited by symptoms at workloads of 5–6 METs.
- Functional class I patients should be capable of achieving workloads in excess of 7–8 METs.

Lead System and Electrode Placement

Electrodes

Obtaining high-quality ECG recordings is the most important aspect for proper interpretation of the ECG stress test. Using appropriate electrodes and proper skin preparation at the site of electrode placement are essential.

- A disposable silver-silver chloride electrode that provides a good skin contact by means of a liquid conductor is the most reliable and optimal electrode.
- Proper skin preparation designed to remove the superficial oils and layer of skin to significantly lower resistance consists of:
  - Cleaning the sites of electrode application with ethyl alcohol.
  - Removing the superficial keratinized layer of epidermis by gentle abrasion.
  - Washing away the removed superficial epidermal layer by a light cleaning such as with acetone.

For the interface between the skin and electrode to be optimal, skin resistance should be reduced to 5000 Ω or less. After electrode placement, the technician should tap lightly on the electrode to assess adequacy of skin preparation (no noise on the ECG should be created with the tap).

In addition, efforts should be taken to minimize motion at the electrode-cable interface. This may be achieved by creating stress loops with precut tape strips or securing the cables centrally with an elastic belt worn around the waist. Disposable mesh vests placed on the upper torso can help secure the electrodes.

For women, particularly those with large breasts, a breast support garment should be worn during the exercise ECG test in order to minimize motion artifacts which can obscure diagnostic ECG changes and hide potentially dangerous arrhythmias during exercise.

Lead Systems

While historically single-channel lead systems such as monitoring lead V5 or bipolar lead CM5 were demonstrated to have high sensitivity for detecting myocardial ischemia compared to 12-lead ECG recordings, current systems utilize multiple ECG leads.

- Use of multiple leads has been shown to increase test sensitivity.
- In recording systems using multiple leads, the lateral precordial leads (leads V4 through V6) are capable of detecting 90% of all instances of ST-segment depression.
- In our laboratory, we monitor leads II, V1, and V5 continuously during stress and recovery. At the end of each stage (and periodically as required), a 12-lead ECG can be displayed and printed.
- The Mason-Likar ("torso") modification of lead placement is used during exercise to minimize muscle and motion artifact.

Observation

Most laboratories continue to use visual observation and interpretation (see Chapter 14) of the exercise ECG. Most modern ECG systems used for exercise testing collect data that would allow for computerized assessment of the exercise ECG test, particularly ST-segment abnormalities, which may enhance the predictive accuracy of the test (see Chapter 20).

Endpoints to Terminate Exercise ECG Stress Tests

A detailed description of the endpoints for the exercise ECG test is provided in Chapter 5. In general, a symptom-limited test (rather than a HR-limited test) to near-maximum level gives the most diagnostic information as well as providing assessment of exercise capacity/prognosis.

The qualified healthcare professional supervising the test must be able to make a correct, instant decision for each patient as to whether the exercise bout should continue or be terminated.

- Encourage the patient to continue when it is apparent that a lack of motivation is present and all parameters show expected (normal) findings.
- It is important to speak with the patient intermittently and to observe facial expression during exercise. These actions may help to assess whether the patient may have any unusual distress. Patients may try to overcome serious symptoms and not report them to the test supervisor.

When to Terminate the Exercise Prematurely

Patient-determined and provider-determined indications are recognized.
Absolute indications include:

- The patient requests that the test stop.
- Significant symptoms, such as chest pain, dizziness, marked dyspnea, or severe fatigue, are produced.
- Signs such as ataxia, pallor, or cyanosis are observed.
- The patient experiences symptoms of an intensity that would prompt stopping daily activities. Do not insist that the patient continue on to reach a predicted HR.
- The patient develops ST-segment elevation (>1.0 mm) in leads without pre-existing Q waves because of prior MI (exceptions: leads aVR, aVL, and V1).
- Occurrence of severe cardiac arrhythmias, such as sustained ventricular tachycardia (VT) or other arrhythmia, including second- or third-degree atrioventricular block, preventing normal maintenance of cardiac output during exercise.
- A decline in systolic BP >10 mmHg occurs despite an increase in workload, when accompanied by any other evidence of myocardial ischemia.
- Development of technical difficulties in the monitoring/interpreting of the ECG or BP.

Relative indications include:

- Marked ST-segment displacement (horizontal or downsloping of >2 mm, measured 60–80 ms after the J point) in a patient with suspected ischemia.
- A decline in systolic BP >10 mmHg (persistently below baseline) despite an increase in workload, in the absence of other evidence of myocardial ischemia.
- Presence of arrhythmias other than sustained VT, including multifocal ventricular ectopy, ventricular triplets, supraventricular tachycardia, and bradyarrhythmias with the potential to become more complex or cause hemodynamic instability.
- Occurrence of an exaggerated hypertensive response, defined as SBP >250 mmHg or diastolic BP >115 mmHg.
- Development of bundle branch block that cannot immediately be distinguished from VT.

Indications Versus Contraindications (see Chapters 3 and 4)

Major Indications of the Exercise ECG Test

- Confirmation or exclusion of CAD; assessment of the etiology of chest pain or equivalent symptom.
- Assessment of functional capacity (exercise tolerance).
- Evaluation of the efficacy of medical and/or surgical treatment for CAD.

Minor Indications of the Exercise ECG Test

- Assessment of the nature of certain (exercise-induced) cardiac arrhythmias and chronotropic incompetence.
- Evaluation of exercise-related symptoms.

- Screening purposes (general population, certain occupations, life insurance).
- Rehabilitation of cardiac patients.
- Research purposes.

Contraindications of the Exercise ECG Test

Contraindications can be categorized into absolute versus relative reasons.

Absolute Contraindications

- Acute MI within two days or active unstable angina pectoris.
- Decompensated heart failure (HF).
- Uncontrolled cardiac arrhythmia with hemodynamic compromise.
- Symptomatic severe aortic stenosis.
- Active infective endocarditis.
- Acute pulmonary embolism, pulmonary infarction, or deep vein thrombosis.
- Acute myocarditis or pericarditis.
- Acute aortic syndrome (aortic dissection, intramural hematoma, penetrating ulcer).
- Other acute illness (acute hepatitis, acute renal failure, pneumonia, high fever, etc.).
- Known or suspected obstructive left main coronary artery stenosis.
- Physical or mental disability precluding safe and adequate testing.

Relative Contraindications

- Moderate to severe aortic stenosis with uncertain relation to symptoms.
- Atrial tachyarrhythmias with uncontrolled ventricular rates.

- Acquired advanced or complete heart block.
- Hypertrophic obstructive cardiomyopathy with severe resting gradient.
- Recent stroke or transient ischemic attack.
- Resting hypertension with systolic or diastolic BPs >200/110 mmHg.
- Uncorrected medical conditions such as significant anemia, electrolyte imbalance, and hyperthyroidism.

Interpretations of the ECG Stress Test

As will be discussed further in Chapter 14, several ECG and clinical criteria are examined when interpreting an ECG stress test. With regard to the ECG response itself:

- The most reliable criterion for an abnormal response is occurrence of horizontal or downsloping ST-segment depression ≥1 mm at 60–80 ms after the J point.
- A less common finding is the occurrence of ST-segment elevation >1.0 mm at 60 ms after the J point in leads without pre-existing Q waves because of prior MI (exceptions: leads aVR, aVL, and V1). In subjects without previous infarction, indicated by absence of Q waves on the resting ECG, ST-segment elevation localizes the site of ischemia (most often due to significant subtotal proximal occlusive CAD). In patients with ST-segment elevation and a prior Q-wave MI, the ST-segment elevation in leads with Q waves is believed to be due to abnormal wall motion in the infarct territory or peri-infarction ischemia.
- Functional ST-segment depression (J-point depression) up to 2 mm is considered to be insignificant unless the depression persists beyond 80 ms, so-called "slow-upsloping ST depression." This degree of upsloping ST-segment depression, however, is considered an "equivocal" response.

- Another purported finding indicative of an abnormal exercise ECG response is inversion of U-waves (rare phenomenon).
- Clinically insignificant ECG findings include phenomenon such as isolated T-wave changes, development of bundle branch block, or peaking of the P-waves during or after exercise.

Factors Influencing the Result: False Positive/Negative Stress ECG Tests (see Chapter 15)

The incidence of false positive or false negative stress ECG test results varies depending upon the diagnostic criteria used, prevalence (pre-test likelihood) of CAD in the population, and several other factors.

False “positive” stress ECG test results are more commonly found in women compared to men due to lower prevalence of CAD. Other conditions associated with false positive test results may include use of medications such as digitalis (less commonly encountered today) and diuretics (rare and only when hypokalemia is present) and with ECG abnormalities which affect repolarization such as left bundle branch block, Wolff-Parkinson-White pattern, left ventricular (LV) hypertrophy, and resting ST/T abnormality.

False “negative” results are most commonly encountered when submaximal exercise stress is performed, with borderline significant coronary artery narrowing or in the presence of less extensive CAD (especially single-vessel left circumflex CAD). Use of anti-anginal medications at the time of testing may also lead to a false “negative” result.

Clinical Values of the Exercise ECG Test

In order to better understand the clinical value of the exercise ECG test it is important to be familiar with the concepts of test sensitivity, specificity, predictive value, and prevalence of disease.

Sensitivity of a test refers to the percentage of patients with disease who are detected correctly (abnormal test result).

Sensitivity = True positives / True positives + False negatives

Specificity of a test is the ability of a negative test to identify those who do not have disease.

Specificity = True negatives / True negatives + False positives.

Based on the results of a large meta-analysis of the exercise ECG stress test, the test performance for the detection of angiographically-significant CAD revealed a mean test sensitivity of 68% and a mean test specificity of 77%. In this analysis, a wide range of sensitivities and specificities was found, likely due to the presence of multiple factors including definitions of what constituted significant CAD, disease prevalence in the various populations studied, and conditions that can lead to false positive or negative results as listed above.

Predictive values help to define the diagnostic value of a test; they are highly influenced by the prevalence of disease in the population being tested.

Positive predictive value of an abnormal ("positive") test is the percentage of abnormal tests which indicate presence of disease.

Positive predictive value = True positives / True positives + False positives.

Negative predictive value represents the percentage of normal ("negative") tests that indicate lack of disease.

Negative predictive value = True negatives / True negatives + false negatives.

Bayes' theorem relates that the probability of having disease following performance of the test equals the product of the pre-test probability of having the disease and the probability that the test provided a true result (post-test probability). A test would have a greater positive predictive value and lower negative predictive value when used in a population with a high prevalence of disease. In converse, when used in a population with a lower prevalence of the disease, the same test would be expected to have a higher negative predictive value and lower positive predictive value.

Without doubt, the multistage exercise ECG stress test provides useful information in the evaluation and management of patients with known or suspected CAD in terms of both diagnosis and assessment of functional capacity. When used in a population with an intermediate pre-test likelihood of disease, the predictive value (diagnostic performance) of the test is good. However, the value of the exercise ECG test is limited when dealing with asymptomatic and generally healthy individuals because of the extremely high incidence of false positive test results.

Numerous studies have documented the correlation between the number and location of diseased coronary vessels and the extent and magnitude of ST-segment changes induced by exercise. In general, the presence of ischemia detected during an exercise ECG stress test more often occurs in patients with higher disease prevalence and greater anatomical extent of CAD. Note that while ST-segment depression occurring during an exercise ECG stress test represents the presence of sub-endocardial ischemia; it *does not serve to localize* the anatomical region(s) of ischemia.

Cardiac Arrhythmias and the Exercise ECG Test (Chapter 12)

Various cardiac arrhythmias may be induced or abolished by exercise. Ventricular arrhythmias are seen commonly with exercise in both healthy subjects and in patients with various cardiovascular disorders, particularly CAD.

- CAD may be strongly suspected when serious ventricular arrhythmias (multiform or grouped ventricular premature contractions [VPCs], VT) develop in conjunction with the onset of exercise-induced angina pectoris even in the absence of ST-segment changes.

- Isolated findings of exercise-induced ventricular arrhythmias are not diagnostic of CAD.
- Exercise-induced ventricular arrhythmias may commonly occur in patients with cardiomyopathy or mitral valve prolapse syndrome (MVPS).
- Supraventricular arrhythmias occur less commonly during exercise and their development is not diagnostic of organic heart disease.
- Atrial premature contractions (APCs), with or without grouped beats and short runs of atrial tachycardia (AT), are the most common supraventricular arrhythmias that occur with exercise.

Hemodynamic Responses to Exercise

Monitoring Requirements

- A continuous display of the ECG with periodic print-outs (usually near the end of each stage) is mandatory during the exercise/stress phase and for at least six to eight minutes during the recovery phase for detection of ST-segment changes and cardiac arrhythmias.
- It is essential to measure BP by applying an appropriately-sized cuff to an upper extremity during each stage of stress and for at least six to eight minutes during the recovery phase.
- It is prudent to obtain additional ECG and BP recordings with any change in symptom status, adverse physical signs, and with the occurrence of significant arrhythmias.

Adverse Hemodynamic Responses

- Patients who demonstrate less than expected acceleration of HR (chronotropic incompetence) during a multistage exercise protocol have an increased risk for overt cardiovascular events.

- Some patients with advanced CAD may develop actual slowing of the HR during progressive exercise. This finding is often associated with angina pectoris, but not necessarily with ST-segment shifts.
- A less than expected increment of the sinus rate during exercise may also be a manifestation of sick sinus syndrome.
- Multi-vessel CAD should be suspected when a reproducible and sustained reduction of SBP of ≥10 mmHg occurs during exercise, especially when angina pectoris and/or ST-segment changes coincide. This type of response may occur in approximately 5% of exercise ECG stress tests in a busy stress laboratory. While the majority of such patients are found to have normal LV function at rest, LV dysfunction may have been present at rest or developed with exercise.
- An exaggerated SBP response to exercise is considered to have occurred when maximal value is ≥210 mmHg for men and ≥190 mmHg for women. A rise in DBP during exercise of >10 mmHg above the resting value or an absolute value of 90 mmHg is considered abnormal and could predict increased likelihood of CAD. Recommended relative indications for exercise test termination are SBP of >250 mmHg and/or a DBP >115 mmHg.
- The healthcare professional monitoring the stress test must be able to distinguish pathological responses of HR and BP during exercise stress from similar responses that may occur during the first stage of exercise among normal individuals who are anxious prior to the exercise ECG test.

Complications and Potential Risks (Chapters 12 and 21)

Overall, exercise testing is considered a safe procedure with a low risk of morbidity and mortality: the incidence of an acute coronary event or cardiac death is estimated to be 1/10 000 cases. Nonetheless, associated cardiovascular events such as serious cardiac arrhythmias (particularly ventricular tachyarrhythmias), acute MI, or even cardiac death may occur during or after stress testing. Careful consideration of contraindications should be reviewed prior to testing and all appropriate precautions and monitoring should be taken during and following the stress testing bout to prevent potentially major complications from occurring.

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