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ABC of clinical electrocardiography

Exercise tolerance testing

Jonathan Hill, Adam Timmis

Exercise tolerance testing is an important diagnostic and prognostic tool for assessing patients with suspected or known ischaemic heart disease. During exercise, coronary blood flow must increase to meet the higher metabolic demands of the myocardium. Limiting the coronary blood flow may result in electrocardiographic changes. This article reviews the electrocardiographic responses that occur with exercise, both in normal subjects and in those with ischaemic heart disease.

Clinical relevance

Exercise tolerance testing (also known as exercise testing or exercise stress testing) is used routinely in evaluating patients who present with chest pain, in patients who have chest pain on exertion, and in patients with known ischaemic heart disease.

Prognostic indications for exercise testing

- Risk stratification after myocardial infarction
- Risk stratification in patients with hypertrophic cardiomyopathy
- Evaluation of revascularisation or drug treatment
- Evaluation of exercise tolerance and cardiac function
- Assessment of cardiopulmonary function in patients with dilated cardiomyopathy or heart failure
- Assessment of treatment for arrhythmia

Exercise testing has a sensitivity of 78% and a specificity of 70% for detecting coronary artery disease. It cannot therefore be used to rule in or rule out ischaemic heart disease unless the probability of coronary artery disease is taken into account. For example, in a low risk population, such as men aged under 30 years and women aged under 40, a positive test result is more likely to be a false positive than true, and negative results add little new information. In a high risk population, such as those aged over 50 with typical angina symptoms, a negative result cannot rule out ischaemic heart disease, though the results may be of some prognostic value.

Exercise testing is therefore of greatest diagnostic value in patients with an intermediate risk of coronary artery disease.

The test

Protocol

The Bruce protocol is the most widely adopted protocol and has been extensively validated. The protocol has seven stages, each lasting three minutes, resulting in 21 minutes' exercise for a complete test. In stage 1 the patient walks at 1.7 mph (2.7 km) up a 10% incline. Energy expenditure is estimated to be 4.8 METs (metabolic equivalents) during this stage. The speed and incline increase with each stage. A modified Bruce protocol is used for exercise testing within one week of myocardial infarction.

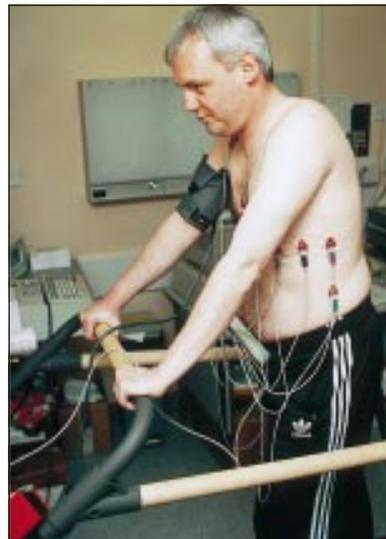
Preparing the patient

β Blockers should be discontinued the day before the test, and digoxin (which may cause false positive results, with ST segment abnormalities) should be stopped one week before testing.

ST segment depression (horizontal or downsloping) is the most reliable indicator of exercise-induced ischaemia

Diagnostic indications for exercise testing

- Assessment of chest pain in patients with intermediate probability for coronary artery disease
- Arrhythmia provocation
- Assessment of symptoms (for example, presyncope) occurring during or after exercise



Patient exercising on treadmill

Workload

- Assessment of workload is measured by metabolic equivalents (METs)
- Workload is a reflection of oxygen consumption and hence energy use
- 1 MET is 3.5 ml oxygen/kg per minute, which is the oxygen consumption of an average individual at rest
- To carry out the activities of daily living an exercise intensity of at least 5 METs is required

The patient is first connected to the exercise electrocardiogram machine. Resting electrocardiograms, both sitting and standing, are recorded as electrocardiographic changes, particularly T wave inversion, may occur as the patient stands up to start walking on the treadmill. A short period of electrocardiographic recording during hyperventilation is also valuable for identifying changes resulting from hyperventilation rather than from coronary ischaemia.

During the test the electrocardiogram machine provides a continuous record of the heart rate, and the 12 lead electrocardiogram is recorded intermittently. Blood pressure must be measured before the exercise begins and at the end of each exercise stage. Blood pressure may fall or remain static during the initial stage of exercise. This is the result of an anxious patient relaxing. As the test progresses, however, systolic blood pressure should rise as exercise increases. A level of up to 225 mm Hg is normal in adults, although athletes can have higher levels. Diastolic blood pressure tends to fall slightly. The aim of the exercise is for the patient to achieve their maximum predicted heart rate.

Safety

If patients are carefully selected for exercise testing, the rate of serious complications (death or acute myocardial infarction) is about 1 in 10 000 tests (0.01%). The incidence of ventricular tachycardia or fibrillation is about 1 in 5000. Full cardiopulmonary resuscitation facilities must be available, and test supervisors must be trained in cardiopulmonary resuscitation.

Limitations

The specificity of ST segment depression as the main indicator of myocardial ischaemia is limited. ST segment depression has been estimated to occur in up to 20% of normal individuals on ambulatory electrocardiographic monitoring. There are many causes of ST segment changes apart from coronary artery disease, which confound the result of exercise testing. If the resting electrocardiogram is abnormal, the usefulness of an exercise test is reduced or may even be precluded. Repolarisation and conduction abnormalities—for example, left ventricular hypertrophy, left bundle branch block, pre-excitation, and effects of digoxin—preclude accurate interpretation of the electrocardiogram during exercise, and as a result, other forms of exercise test (for example, adenosine or dobutamine scintigraphy) or angiography are required to evaluate this group of patients.

Normal trace during exercise

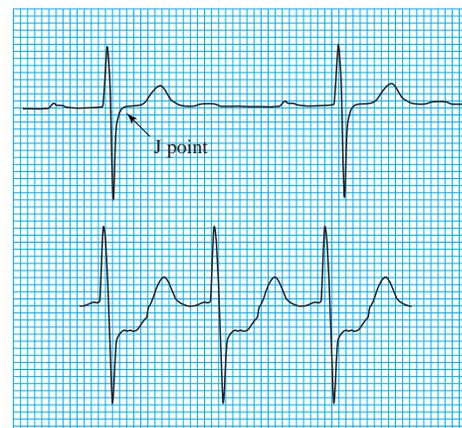
The J point (the point of inflection at the junction of the S wave and ST segment) becomes depressed during exercise, with maximum depression at peak exercise. The normal ST segment during exercise therefore slopes sharply upwards.

Maximum predicted heart rate

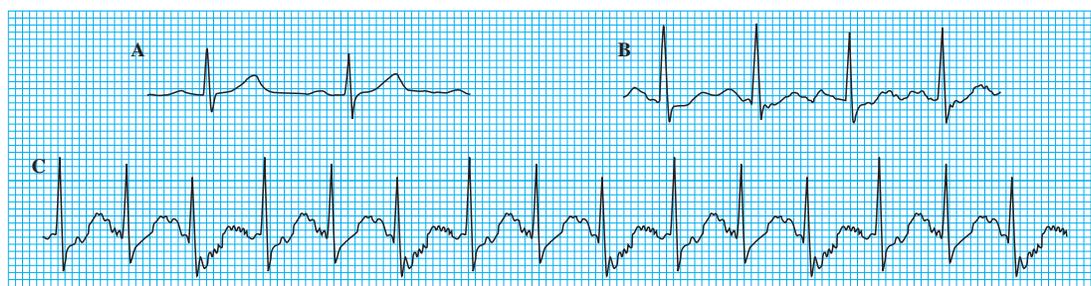
- By convention, the maximum predicted heart rate is calculated as 220 (210 for women) minus the patient's age
- A satisfactory heart rate response is achieved on reaching 85% of the maximum predicted heart rate
- Attainment of maximum heart rate is a good prognostic sign

Contraindications for exercise testing

- Acute myocardial infarction (within 4-6 days)
- Unstable angina (rest pain in previous 48 hours)
- Uncontrolled heart failure
- Acute myocarditis or pericarditis
- Acute systemic infection
- Deep vein thrombosis
- Uncontrolled hypertension (systolic blood pressure > 220 mm Hg, diastolic > 120 mm Hg)
- Severe aortic stenosis
- Severe hypertrophic obstructive cardiomyopathy
- Untreated life threatening arrhythmia
- Dissecting aneurysm
- Recent aortic surgery



Top: At rest. Bottom: Pathological ST segment depression as measured 80 ms from J point



Normal changes from rest (A), after three minutes' exercise (B), and after six minutes' exercise (C). Note the upsloping ST segments

By convention, ST segment depression is measured relative to the isoelectric baseline (between the T and P waves) at a point 60-80 ms after the J point. There is intraobserver variation in the measurement of this ST segment depression, and therefore a computerised analysis that accompanies the exercise test can assist but not replace the clinical evaluation of the test.

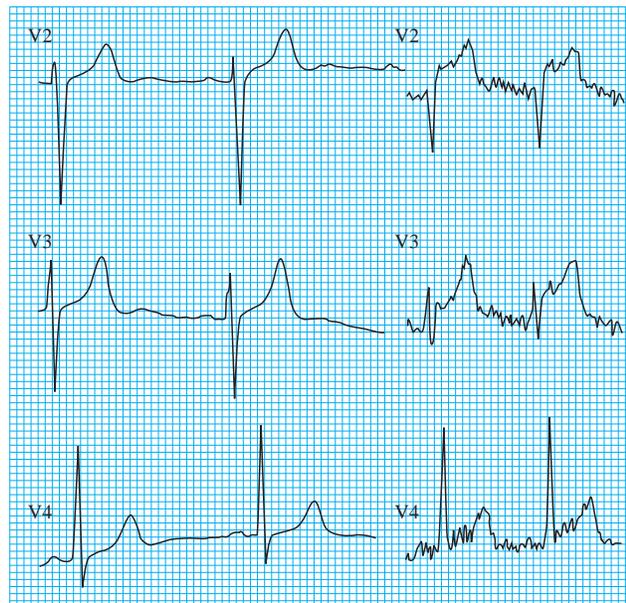
Normal electrocardiographic changes during exercise

- P wave increases in height
- R wave decreases in height
- J point becomes depressed
- ST segment becomes sharply upsloping
- Q-T interval shortens
- T wave decreases in height

Abnormal changes during exercise

The standard criterion for an abnormal ST segment response is horizontal (planar) or downsloping depression of > 1 mm. If 0.5 mm of depression is taken as the standard, the sensitivity of the test increases and the specificity decreases (vice versa if 2 mm of depression is selected as the standard).

Other recognised abnormal responses to exercise include ST elevation of > 1 mm, particularly in the absence of Q waves. This suggests severe coronary artery disease and is a sign of poor prognosis. T wave changes such as inversion and pseudo-normalisation (an inverted T wave that becomes upright) are non-specific changes.

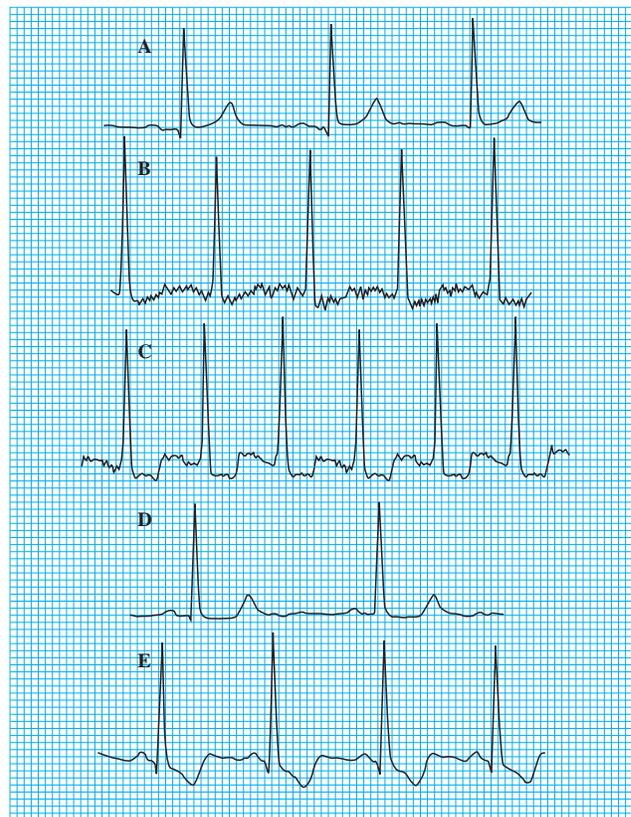


ST segments in leads V2 to V4 at rest (left) and after two minutes' exercise (right) (note obvious ST elevation)

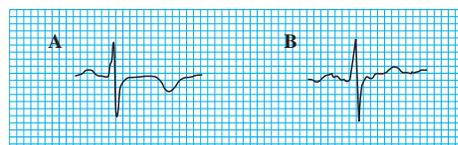
A highly specific sign for ischaemia is inversion of the U wave. As U waves are often difficult to identify, especially at high heart rates, this finding is not sensitive. The presence of extrasystoles that have been induced by exercise is neither sensitive nor specific for coronary artery disease.

Stopping the test

In clinical practice, patients rarely exercise for the full duration (21 minutes) of the Bruce protocol. However, completion of 9-12 minutes of exercise or reaching 85% of the maximum predicted changes in heart rate is usually satisfactory. An



Horizontal ST segment depression (A=at rest, B=after three minutes' exercise, C=after six minutes' exercise) and downsloping ST segment depression (D=at rest, E=after six minutes' exercise)



T wave inversion in lead V5 at rest (A) and normalisation of T waves with exercise (B)

Reasons for stopping a test

Electrocardiographic criteria

- Severe ST segment depression (> 3 mm)
- ST segment elevation > 1 mm in non-Q wave lead
- Frequent ventricular extrasystoles (unless the test is to assessment ventricular arrhythmia)
- Onset of ventricular tachycardia
- New atrial fibrillation or supraventricular tachycardia
- Development of new bundle branch block (if the test is primarily to detect underlying coronary disease)
- New second or third degree heart block
- Cardiac arrest

Symptoms and signs

- Patient requests stopping because of severe fatigue
- Severe chest pain, dyspnoea, or dizziness
- Fall in systolic blood pressure (> 20 mm Hg)
- Rise in blood pressure (systolic > 300 mm Hg, diastolic > 130 mm Hg)
- Ataxia

exercise test should end when diagnostic criteria have been reached or when the patient's symptoms and signs dictate.

After the exercise has stopped, recording continues for up to 15 minutes. ST segment changes (or arrhythmias) may occur during the recovery period that were not apparent during exercise. Such changes generally carry the same significance as those occurring during exercise.

The most common reason for stopping an exercise test is fatigue and breathlessness as a result of the unaccustomed exercise



Marked ST changes in recovery but not during exercise

Interpreting the results

Diagnostic testing

Any abnormal electrocardiographic changes must be interpreted in the light of the probability of coronary artery disease and physiological response to exercise. A normal test result or a result that indicates a low probability of coronary artery disease is one in which 85% of the maximum predicted heart rate is achieved with a physiological response in blood pressure and no associated ST segment depression.

A test that indicates a high probability of coronary artery disease is one in which there is substantial ST depression at low work rate associated with typical angina-like pain and a drop in blood pressure. Deeper and more widespread ST depression generally indicates more severe or extensive disease.

False positive results are common in women, reflecting the lower incidence of coronary artery disease in this group.

Prognostic testing

Exercise testing in patients who have just had a myocardial infarction is indicated only in those in whom a revascularisation procedure is contemplated; a less strenuous protocol is used. Testing provides prognostic information. Patients with low exercise capacity and hypotension induced by exercise have a poor prognosis. Asymptomatic ST segment depression after myocardial infarction is associated with a more than 10-fold increase in mortality compared with a normal exercise test. Conversely, patients who reach stage 3 of a modified Bruce protocol with a blood pressure response of >30 mm Hg have an annual mortality of $<2\%$. Exercise testing can also add prognostic information in patients after percutaneous transluminal coronary angiography or coronary artery bypass graft.

Screening

Exercise testing of asymptomatic patients is controversial because of the high false positive rate in such individuals. Angina remains the most reliable indicator of the need for further investigation.

In certain asymptomatic groups with particular occupations (for example, pilots) there is a role for regular exercise testing, though more stringent criteria for an abnormal test result (such as ST segment depression of >2 mm) should be applied. In the United Kingdom, drivers of heavy goods vehicles and public service vehicles have to achieve test results clearly specified by the Driver and Vehicle Licensing Agency before they are considered fit to drive.

Findings suggesting high probability of coronary artery disease

- Horizontal ST segment depression of ≤ 2 mm
- Downsloping ST segment depression
- Early positive response within six minutes
- Persistence of ST depression for more than six minutes into recovery
- ST segment depression in five or more leads
- Exertional hypotension

Rationale for testing

- Bayes's theorem of diagnostic probability states that the predictive value of an abnormal exercise test will vary according to the probability of coronary artery disease in the population under study
- Exercise testing is therefore usually performed in patients with a moderate probability of coronary artery disease, rather than in those with a very low or high probability

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The ABC of clinical electrocardiography is edited by Francis Morris, consultant in emergency medicine at the Northern General Hospital, Sheffield; June Edhouse, consultant in emergency medicine, Stepping Hill Hospital, Stockport; William J Brady, associate professor, programme director, and vice chair, department of emergency medicine, University of Virginia, Charlottesville, VA, USA; and John Camm, professor of clinical cardiology, St George's Hospital Medical School, London. The series will be published as a book in the summer.