

Preoperative cardiopulmonary exercise testing

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Patients with cardiorespiratory disease have an increased risk of perioperative complications. Several prediction tools have been developed in an attempt to quantify this risk. Goldman, Detsky, and Lee each produced scoring systems to predict the likelihood of cardiac complications and Arozullah provides us with a risk prediction equation for postoperative respiratory failure. These focus on only a single organ and make little assessment of the severity of each contributing risk factor.

Overall risk also depends on the type of surgery with thoracic and intra-abdominal procedures associated with the highest complication rates. Direct complications of surgery or anaesthesia account for only 1% of overall mortality. The majority of adverse events are therefore linked to the severity of pre-existing cardiorespiratory disease and the functional ability of patients to meet the extra metabolic demands required when undertaking significant surgery.

Patient history

The Duke Activity Status Index represents a simple patient completed questionnaire which ascertains the maximum level of physical activity that an individual is able to perform. From this score, the predicted peak oxygen consumption can be calculated. One metabolic equivalent (MET) represents the oxygen consumption of an adult at rest ($\sim 3.5 \text{ ml kg}^{-1} \text{ min}^{-1}$). Varying degrees of exercise are assigned a number of METs. Patients should be able to perform >4 METs, which is equivalent to climbing at least one flight of stairs, if they are to consider undertaking major surgery. Unfortunately, patients' estimations of their exercise capabilities are very subjective and are frequently overestimated.

Widely available tests such as echocardiogram and spirometry provide limited information as they are performed at rest. Treadmill exercise ECG testing requires weight-bearing coordinated activity which can be difficult for some elderly patients and has a low sensitivity

(46%) and specificity (66%) to diagnose coronary artery disease.¹

Cardiopulmonary exercise testing

CPET is the most reliable and objective test for evaluation of functional capacity. Originally confined to research laboratories, CPET has evolved through the application of a detailed knowledge of the normal physiological responses to exercise and the patterns of change that occur in a variety of disease states. It uses technology that is familiar to the anaesthetist, including monitoring of inspired and expired gases and continuous ECG, NIAP, and Sp_{O_2} . Computer technology allows the capture and graphical display of the numerous measurements obtained.

Performing the test

An adequately ventilated room with full resuscitation facilities is required and two members of staff are advisable: one to instruct and look after the patient and the other to observe the monitors and to run the test.

The equipment consists of a metabolic cart and a static cycle. The metabolic cart contains a gas analyser, a computer and screens which display the continuous 12-lead ECG, with ST segment analysis, and graphical displays of the physiological changes occurring during exercise. The gas analysers should have a response time of <90 ms to enable breath-by-breath measurement of oxygen consumption (VO_2) and carbon dioxide production (VCO_2). Gas flows and volumes are quantified by a pressure differential pneumotachograph attached to the patient's mouthpiece. The gas analyser and flow meter are calibrated before every test. The cycle ergometer is linked to the computer, so that the resistance can be increased in a controlled manner and the work performed by the patient can be recorded.

Despite being safe with a reported mortality of 2–4 in 100 000, patients should be clinically

Key points

Cardiopulmonary exercise testing (CPET) provides a safe, reliable, repeatable, non-invasive, objective, individual assessment of combined pulmonary, cardiac, and circulatory function.

It quantifies the functional ability to respond to the increased metabolic demands of major surgery generating a patient-specific measure of risk.

Anaerobic threshold (AT) marks the onset of anaerobic metabolism as a result of inadequate oxygen delivery and is not altered by patient effort.

It is usually reached half way through an incremental exercise test, has been found to predict postoperative morbidity and mortality, and can help triage the patient to an appropriate postoperative care facility.

Functional walk tests provide a simple alternative measurement of global cardiorespiratory function.

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evaluated before CPET to exclude contraindications which are listed in Table 1. Approximately 60% of arthritic patients awaiting major joint replacement will be able to complete the test.² Informed consent should also be obtained.

Before commencing the test, the cycle ergometer saddle height should be adjusted and the patient coached in pedalling at a constant speed of between 50 and 60 rpm as indicated on the cycle's display. Twelve-lead ECG, NIAP, and Sp_o₂ monitors are attached and a mouthpiece or tight-fitting mask applied. Pre-test spirometry can be performed at this stage.

The rate of increment in work rate can be predetermined by the following formulae to ensure that the duration of exercise is between 6 and 10 min.

$$\text{Work rate increment (W min}^{-1}\text{)} = \frac{\text{peak VO}_2 - \text{VO}_2 \text{ unloaded}}{100}$$

$$\text{Peak VO}_2 \text{ (ml min}^{-1}\text{) men} = \text{height (cm)} - \text{age (yr)} \times 20$$

$$\text{Peak VO}_2 \text{ (ml min}^{-1}\text{) women} = \text{height (cm)} - \text{age (yr)} \times 14$$

$$\text{VO}_2 \text{ unloaded (ml min}^{-1}\text{)} = 150 + [6 \times \text{weight (kg)}]$$

During the first phase of the test, resting baseline values are recorded for 3 min. Then, the patient starts pedalling without any resistance. Following this 1–3 min period of unloaded cycling, a continuously increasing resistance is applied to the cycle ergometer at the predetermined ramp rate.

During the test, the patient is unable to speak because of the mouthpiece, but can communicate using previously agreed signs. The severity of symptoms such as chest pain, leg pain, or breathlessness can be collected every minute using pointing charts such as the Borg scale. Verbal encouragement is required to help patients continue until a true peak exercise limit has been reached. The test can be terminated by the patient at any time, usually

because of breathlessness or exhaustion, or by the technician if complications arise such as significant ST changes or new dysrhythmias. Full monitoring continues in the recovery period for 10 minutes after cessation of exercise.

Measurements

The average CPET records ~5000 measurements. These include work rate in watts and metabolic gas exchange parameters such as oxygen consumption (VO₂), carbon dioxide production (VCO₂), respiratory exchange ratio (RER) and anaerobic threshold (AT). Cardiovascular parameters include heart rate, 12 lead ECG with ST analysis, NIAP, and oxygen pulse (VO₂/HR) which approximates stroke volume. Ventilatory measurements include minute ventilation (VE), tidal volume (VT) and respiratory rate. Pulmonary gas exchange can be assessed by measuring Sp_o₂, ventilatory equivalents for oxygen (VE/VO₂) and carbon dioxide (VE/VCO₂) and P_E'CO₂ and P_E'O₂.

Computer software packages are available to calculate expected normal physiological variables according to height, weight, age, and sex. To aid reporting, readings are displayed graphically in a standardized format called the nine-panel plot (Fig. 1).

Numbered 1–9 from top left to bottom right, panels 2, 3, and 5 relate to the cardiovascular system, panels 1, 4, and 7 examine ventilation, and panels 6, 8, and 9 look at the ventilation perfusion relationships.

As the work rate increases, exercising muscle requires more oxygen to generate adequate levels of ATP. This increase in oxygen consumption has to be met by increasing cardiac output. VO₂ is equal to cardiac output multiplied by arterial-mixed venous oxygen difference. Cardiac output increases linearly with VO₂ (~6 litre min⁻¹ cardiac output per litre VO₂) in most patients, as does arterial-mixed oxygen difference until a peak oxygen extraction

Table 1 Absolute and relative contraindications for cardiopulmonary exercise testing

Absolute	Relative
Acute myocardial infarction (3–5 days)	Left main coronary stenosis or its equivalent
Unstable angina	Moderate stenotic valvular heart disease
Uncontrolled arrhythmias causing symptoms or haemodynamic compromise	Severe untreated arterial hypertension at rest (>200 mm Hg systolic, >120 mm Hg diastolic)
Syncope	Tachyarrhythmias or bradyarrhythmias
Active endocarditis	High-degree atrioventricular block
Acute myocarditis or pericarditis	Hypertrophic cardiomyopathy
Symptomatic severe aortic stenosis	Significant pulmonary hypertension
Uncontrolled heart failure	Advanced or complicated pregnancy
Acute pulmonary embolus or pulmonary infarction	Electrolyte abnormalities
Thrombosis of lower extremities	Orthopaedic impairment that compromises performance
Suspected dissecting aneurysm	
Uncontrolled asthma	
Pulmonary oedema	
Room air desaturation at rest <85%	
Respiratory failure	
Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis)	
Mental impairment leading to inability to cooperate	

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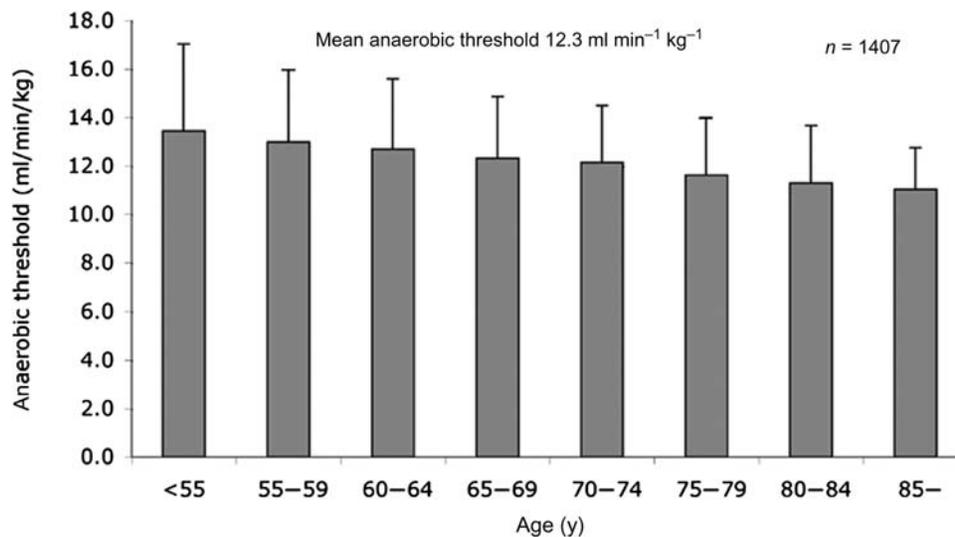


Fig 2 Distribution of preoperative AT according to age group. (Reproduced from P. Older and colleagues, <http://www.cpxtesting.com> with permission.)

ventilatory equivalents for oxygen and the end-tidal P_{O_2} begins to increase.

Most patients will be able to pass their AT as it is normally reached about half way through a CPET. Peak VO_2 represents the maximum VO_2 that is measured, usually at the point that exercise is terminated. The AT, however, will not vary with patient motivation and therefore provides a reliable, repeatable, patient-specific measurement of dynamic functional capacity.

AT does not vary greatly with age (Fig. 2), but will be reduced in proportion to the degree of organ impairment.

Clinical applications

CPET can differentiate the cause of dyspnoea and provides a powerful diagnostic and prognostic tool for a variety of medical disorders, including coronary artery disease, cardiac failure, and restrictive and obstructive lung disease. It also provides a detailed evaluation of patients' functional status before major surgery.

Major intra-cavity surgery generates a significant systemic inflammatory response. This is associated with an increase in oxygen consumption from $110 \text{ ml min}^{-1} \text{ m}^{-2}$ at rest to $\sim 170 \text{ ml min}^{-1} \text{ m}^{-2}$ postoperatively. This represents a requirement to increase VO_2 by 50%. However, as this increase has to be sustained for several days after surgery, substantially greater cardiorespiratory reserve is required.

During exercise, local mechanisms increase OER to 75%, but after an operation OER is only 30%. A relative 2.5-fold increase in postoperative cardiac output is therefore required to match the oxygen delivery seen during exercise.

CPET represents a non-invasive simulation of the requirements of major surgery. Older and colleagues³ in Melbourne have used CPET before major surgery for 15 yr and have published data relating AT to postoperative in-hospital mortality (Fig. 3).

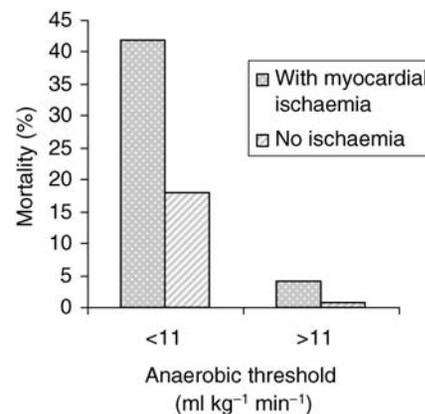


Fig 3 Association of preoperative AT with postoperative mortality in 187 elderly patients undergoing major intra-abdominal surgery. Adapted from Older and colleagues.⁴

An AT of at least $11 \text{ ml kg}^{-1} \text{ min}^{-1}$ is required to safely undertake significant surgery.

Peak VO_2 correlates best with postoperative cardiopulmonary complication rate after oesophagectomy, with figures of at least $800 \text{ ml min}^{-1} \text{ m}^{-2}$ being required to safely undertake this extensive surgery.⁵ CPET before hepatic transplantation has demonstrated that peak $VO_2 < 60\%$ predicted and AT $< 50\%$ of predicted peak VO_2 are both associated with 100 day mortality.⁶

When considering abdominal aortic aneurysm surgery, peak $VO_2 < 20 \text{ ml kg}^{-1} \text{ min}^{-1}$, low AT, and raised ventilatory equivalent for CO_2 are associated with postoperative complications and 30 day mortality.^{7,8} Evaluation of CPET before thoracotomy again demonstrates that low AT and peak VO_2 are associated with poor outcome.⁹

CPET can be used to triage patients' postoperative care facility, rationalizing the use of scarce critical care beds. No postoperative cardiovascular mortality occurs and length of stay is shorter in patients who are sent to the ward after major surgery if they have an AT $>11 \text{ ml kg}^{-1} \text{ min}^{-1}$.^{10,11} Patients with AT $<11 \text{ ml kg}^{-1} \text{ min}^{-1}$ benefit from postoperative critical care.

Interest is growing in pre-surgical exercise training in order to improve patients' cardiorespiratory fitness and hopefully reduce postoperative mortality. CPET before and after such training has demonstrated that it is possible to increase peak VO_2 by an average of $3.3 \text{ ml kg}^{-1} \text{ min}^{-1}$ (20–30%) before operation.¹² Further studies are awaited to determine if this will reduce mortality.

Functional Walk Tests

Simple walk tests utilize an activity that patients are familiar with, are inexpensive, require little equipment and are easy to administer. They can be used to assess functional capacity and provide an alternative when the more comprehensive gold standard CPET is not available. The most widely employed and investigated of these are the 6-minute walk test (6MWT) and the incremental shuttle walk test (ISWT).

The 6MWT measures how far subjects can walk along a flat corridor, turning around cones at each end, at normal pace, in 6 minutes. Median distances are 500–600 m in healthy subjects. Other measurements include SpO_2 , heart rate and the Borg scale assessment of dyspnoea and leg fatigue. The ISWT involves patients walking at speeds that increase every minute by 0.17 m s^{-1} in time to audio signals. Failure to reach the cone before the next tone or exhaustion will stop the test. Distance walked in both tests correlates well with peak VO_2 and maximum work capacity as measured by CPET, although the ISWT is less familiar to patients and more difficult to administer than the 6MWT.

Preoperative studies show that a 6MWT distance of less than 300 m is linked to a poor prognosis following aortic valve replacement for aortic stenosis. A distance of 350 m has been used as a trigger to consider lung volume reduction surgery (LVRS) for management of significant COPD and distances less than 200 m predict high 6-month mortality following LVRS. Heart failure patients with 6MWT distances of less than 400 m are usually considered for transplant. A threshold distance of 350 m on ISWT predicts low mortality after oesophagectomy.¹³

The ISWT is more dependent on patient motivation than 6MWT or CPET. The distance walked in both walk tests varies with age, sex, height and degree of encouragement. Repeated tests also tend to show improvement as the subject learns the technique.

However, AT determined by CPET is not dependent on patient motivation and varies by only 10% in repeated tests,¹⁴ providing a more useful marker of response to therapy. CPET will also provide more specific detail as to why the functional capacity may be reduced and so better guide appropriate preoperative optimization.

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Please see multiple choice questions 1–3