

Adult Cardiopulmonary Exercise Testing

Respiratory Science

1. Purpose

This guideline provides recommendations regarding best practice to support high quality cardiopulmonary exercise testing throughout Queensland Health.

2. Scope

This guideline provides information for clinical measurement practitioners who perform cardiopulmonary exercise testing in adults. It outlines the minimum requirements for obtaining acceptable cardiopulmonary exercise testing data in adults.

This guideline does not include specific requirements for paediatric cardiopulmonary exercise testing, nor is it appropriate as a guideline for cardiac exercise stress testing. The guideline for cardiac stress tests can be found at <http://www.health.qld.gov.au/qhpolicy/docs/gdl/qh-gdl-392.pdf>

3. Related documents

This guideline is primarily based on The American Thoracic Society (ATS) / American College of Chest Physicians (ACCP) Statement on Cardiopulmonary Exercise Testing (American Journal of Respiratory and Critical Care Medicine, 2003)¹. References from other sources have been identified in this document.

Authorising Policy and Standard/s:

- [Queensland Health Guide to Informed Decision-making in Healthcare \(2012\)](#)²

Procedures, Guidelines and Protocols:

- [Australian Guidelines for the prevention and control of infection in healthcare](#) (CD33:2010)³
- Queensland Health Guideline (QH-GDL-386:2012)⁴: [Spirometry \(Adult\) guideline](#)
- Queensland Health Guideline (QH-GDL-387:2012)⁵: [Adult and Paediatric Resting Electrocardiography \(ECG\)](#)

Forms and templates:

- Queensland Health Consent form⁶: [Cardiopulmonary Exercise Stress Test \(v4.00 - 02/2011\)](#)

4. Guideline for Performing Cardiopulmonary Exercise Testing

4.1. Emergency Protocol

Staff performing CPET should be familiar with sections 4.4.2 (Absolute and relative contraindications to CPET) and 4.4.3 (Indications for Exercise Termination).

A medical officer must be present during CPET and should closely monitor the patient, paying particular attention to ECG and blood pressure responses. Resuscitation equipment (including defibrillator) should be readily available in the case of a medical emergency. Attending staff must be trained in its use. See Table 1 below for a list of the specific risks of performing CPET.

Follow all Health & Hospital Service protocols in the event of an emergency.

Table 1: Specific Risks of Performing CPET (adapted from references 1 and 6)

RISK	LIKELIHOOD
Shortness of breath, musculoskeletal discomfort, mild angina	Common – more than 5% of tests performed
Low blood pressure, chest pain	Uncommon – 1 to 5%
Fainting, prolonged cardiac arrhythmia, myocardial infarction	Rare – less than 1%
Death	Extremely rare - 2 to 5 per 100,000 tests

4.2. Infection Control Procedures

Adhere to relevant Hospital and Health Service infection control protocols and procedures at all times when performing CPET.

Australian Guidelines for the prevention and control of infection in healthcare (2010)³
<http://www.nhmrc.gov.au/node/30290>

4.3. Gaining Consent

Obtain the patient's consent in accordance with Queensland Health's Informed Decision-making in Healthcare Policy².

All patients must be provided with the Queensland Health Consent form for Cardiopulmonary Exercise Testing⁶ before commencing the test. A medical officer must complete the consent form with the patient.

4.4. Identifying Indications/Contraindications

4.4.1 Indications to CPET ¹

- Evaluation of exercise tolerance and functional work capacity:
 1. Determination of exercise-limiting factors and pathophysiologic mechanisms.
- Evaluation of undiagnosed exercise intolerance:
 1. Assessing the contribution of cardiac and pulmonary aetiology in coexisting disease
 2. Symptoms disproportionate to resting pulmonary and cardiac tests
 3. Unexplained dyspnoea after initial other testing.
- Evaluation of patients with respiratory and/or cardiovascular disease:
 1. Functional evaluation and prognosis in patients with heart failure
 2. Selection for cardiac transplantation.
 3. Chronic obstructive pulmonary disease:
 - Establishing exercise limitation(s)
 - Determining the magnitude of hypoxaemia.
 4. Interstitial lung diseases:
 - Detecting gas exchange abnormalities
 - Determining the magnitude of hypoxaemia
 - Determining potential exercise-limiting factors.
- Pre-operative evaluation
- Evaluation of response to treatment following surgery, rehabilitation, or pharmacological treatment
- Quantification of impairment for medico-legal purposes.

4.4.2 Absolute and relative contraindications to CPET ^{1,7}

Absolute

- Recent myocardial infarction (7 days)
- Unstable angina
- Uncontrolled arrhythmias
- Syncope
- Active endocarditis
- Acute myocarditis or pericarditis
- Severe aortic stenosis
- Uncontrolled heart failure
- Acute pulmonary embolus or pulmonary infarct
- Thrombosis of the lower extremities
- Suspected dissecting aneurysm
- Uncontrolled asthma
- Pulmonary oedema
- Room air oxygen desaturation < 85%
- Type I hypoxaemic respiratory failure
- Severe mental impairment or any other inability to consent.

Relative

- Left main coronary stenosis
- Stenotic valvular heart disease
- Severe hypertension at rest ($\geq 200/120$ mmHg)
- Tachyarrhythmia or bradyarrhythmia
- Atrial fibrillation with uncontrolled ventricular rate
- High degree AV block
- Hypertrophic cardiomyopathy
- Significant pulmonary hypertension
- Advanced/complicated pregnancy
- Orthopaedic impairment.

Despite the patient presenting for a CPET following a medical consult, it is very important to consider the contraindications to testing before commencing the test.

Relative contraindications can be superseded if the benefits of conducting the test outweigh the risks.

If there is any doubt as to the suitability of the patient undergoing a CPET, discuss it further with the referring physician.

4.4.3 Indications for Exercise Termination ¹

- Orthopaedic impairment
- Chest pain suggestive of ischaemia
- Ischaemic ECG changes, specifically ST elevation (> 1 mm) in leads without Q waves (other than V1 or aVR), ST or QRS changes such as excessive ST displacement (horizontal or downsloping of > 2 mm) or marked axis shift⁸
- Complex ectopy
- Second or third degree heart block
- Fall in systolic pressure > 20 mmHg from the highest value during the test
- Hypertension (> 250 mmHg systolic; > 120 mmHg diastolic)
- Severe desaturation; $SpO_2 \leq 80\%$ with accompanied symptoms and signs of hypoxemia
- Sudden pallor
- Loss of coordination
- Mental confusion
- Dizziness or faintness
- Signs of respiratory failure

4.5. Facilities and equipment

4.5.1 Testing facility

- For safety and infection control purposes, clearly defined rooms should be available for CPET. Whilst there are no recent published guidelines on the design of an exercise laboratory, recent Australian standards exist for design and layout of a general measurement laboratory⁹.
- The US Department of Veteran’s Affairs 1988 publication¹⁰ suggests a CPET laboratory should be a minimum 249 ft² (23.1 m²) in size.

4.5.2 Equipment

The following equipment / supplies are required for CPET:

- An integrated CPET module including the following:
 - Cycle ergometer (preferred) or treadmill (see table 2)
 - 12-lead ECG monitoring system
 - Pulse oximeter
 - Flow sensor (pneumotachograph or similar)
 - Oxygen and carbon dioxide gas analysers
 - Software to operate the integrated components
- 3L calibration syringe (certified) for volume calibration
- Calibration gases for 2-point calibration of gas analysers
- Disposable nose clips, bacterial/viral filters and/or rubber flanged mouthpiece, (saliva trap optional)
- Sphygmomanometer and stethoscope
- Modified Borg scale
- Resuscitation and other emergency equipment (see 4.1 Emergency Protocol).

Table 1: CPET Equipment – Cycle Ergometry Vs Treadmill
(adapted from reference 1)

	CYCLE	TREADMILL
VO₂max	Lower	Higher
Work rate measurement	Yes	No
Noise and artefact	Less	More
Safety	Safer	Possibly less safe
Weight bearing in obese*	Less	More
Degree of leg muscle training	Less	More
More appropriate for:	Patients	Active normal subjects

* dependent on individual weight limitations of ergometer and treadmill

Cycle ergometers are generally safer, more appropriate for a wider range of subjects and provide an accurate measurement of work rate. Therefore a cycle ergometer is recommended over a treadmill.

4.6. Personnel and training requirements

- CPET must be performed in a laboratory under the direction of a physician, typically a respiratory or cardiac physician, with experience and training in exercise physiology, with knowledge of calibration, quality assurance, performance and interpretation of CPET.
- Each CPET must be supervised by a medical officer. Where feasible, supervision by a senior registrar is encouraged, as supervision of CPET forms an important aspect of their advanced training. The attending doctor must be trained in Advanced Life Support, use of resuscitation equipment and must also have initial training in the supervision of exercise tests (e.g. have a doctor experienced in CPET with them during supervision of the first few tests).
- All scientists performing CPET should be trained in a field related to exercise testing (respiratory, cardiac or exercise science). They must be able to recognise an abnormal cardiac rhythm and ST changes on ECG, and should have a minimum of 3 months supervision before being solely responsible for the performance of CPET¹.
- Due to the complex nature of CPET, staff can quickly become deskilled in performing this test. It is recommended that scientific and medical directors remain cognisant of the need to maintain competency in this specialised area of testing within the respiratory laboratory.

4.7. Test Procedure

4.7.1 Patient preparation¹

- Suitable attire, including comfortable clothing and appropriate footwear should be worn
- Normal medical regimes should be adhered to (i.e. use of prescription medication) unless instructed otherwise by the referring physician
- Patients should abstain from smoking for at least 8 hours prior to testing
- The patient should not exercise heavily on the day of testing and be well rested before the test
- Heavy meals are to be avoided, with a light meal eaten no less than 2 hours prior to the test
- A CPET worksheet should be completed for each patient by the supervising scientist (see Appendix A for an example worksheet). It is important to record the patient's current medications and make these known to the supervising medical officer. The supervising medical officer should complete the ECG comment section and any other relevant general comments that can aid in interpretation of the test.

Pre-Test Respiratory Function Testing

- Prior to the CPET the patient is required to perform a flow volume loop:
 - Queensland Health Guideline (QH-GDL-386:2012)⁴: [Spirometry \(Adult\) guideline](#)
- The flow volume loop is used in several ways:
 - FEV₁ (the forced expired volume in one second, obtained from spirometry) is used in the calculation of the workload increment used (see Exercise Phase under section 4.7.2 Performing CPET and Data Collection).
 - FEV₁ may also be used to estimate maximal voluntary ventilation (MVV), using FEV₁ x 39.3. This calculation has been shown to give an MVV closest to the gold standard of measuring MVV over a 12 second period^{11, 12}.
 - As a baseline measurement of inspiratory capacity (IC) and end-expiratory lung volume (EELV) when evaluating exercise flow-volume loops (see Exercise Flow-Volume Loops further along in this section).

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- The MVV can be measured directly¹, although it can be estimated as stated above. The calculated MVV may be inaccurate in the presence of increased inspiratory resistance or respiratory muscle weakness. The method used to measure MVV is as described in Miller et al.¹³

Medical Supervision

- The CPET requires a medical officer to be present throughout the test and in the immediate recovery period.
- Relevant medical history should be available at time of testing (e.g. Patient chart, or most recent detailed letter from the referring specialist).

Patient Consent

- Written patient consent must be obtained before testing:
 - Queensland Health Consent form⁶: [Cardiopulmonary Exercise Stress Test \(v4.00 - 02/2011\)](#)
- The reason for the CPET should be clearly explained, including the risks and benefits of the test.
- The patient should be told that they are required to give a “maximal effort”.
- They should be warned that they may feel discomfort, particularly close to maximal exertion.
- It should be explained that the test can be stopped at any time if the patient feels “extreme breathlessness, chest pain, light-headed, or nauseated”.
- The supervising medical officer must gain signed patient consent before proceeding with the test. Wherever feasible, signed patient consent should be obtained by the referring clinician before the patient attends for testing.

Electrocardiogram (ECG) Preparation

- A 12-lead ECG is required for each CPET:
 - Queensland Health Guideline (QH-GDL-387:2012)⁵: [Adult and Paediatric Resting Electrocardiography \(ECG\)](#)
- Skin preparation is essential for reliable, artefact free ECG monitoring.
- Skin preparation involves the removal of body hair from electrode sites with a new disposable razor.
- This is followed by cleaning the electrode areas with alcohol to remove skin oils and dirt.
- Scratching the next layer of skin will further reduce artefact.
- A resting ECG should be taken with the patient sitting still in a chair, prior to sitting on the cycle ergometer. The ECG is monitored throughout the exercise test and during recovery.

Lead Placement (see Figure 1):

RA & LA: Slightly below the right and left clavicle.

RL & LL: Level of the umbilicus at the mid clavicular line.

V1: Fourth intercostal space at the right border of the sternum.

V2: Fourth intercostal space at the left border of the sternum.

V3: Midway between V2 & V4.

V4: At the mid-clavicular line in the 5th intercostal space.

V5: At the anterior axillary line on the same horizontal level as V4.

V6: At the mid-axillary line on the same horizontal level as V4 & V5.

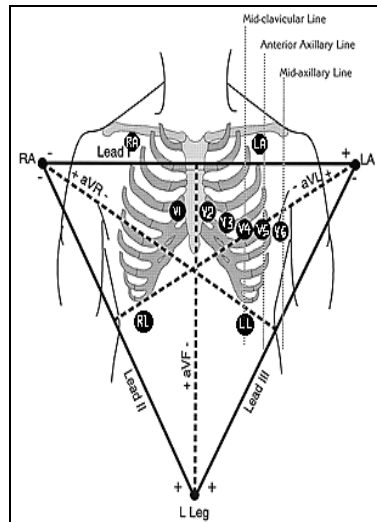


Figure 1: Electrode Placement

Oximetry Preparation

- Oximetry is measured transcutaneously via a finger.
- Wipe the site with an alcohol swab.
- Ensure there is a good arterial wave throughout the test.
- Ensure the heart rate reading from the pulse oximeter matches the ECG heart rate.

Resting Blood Pressure

- Blood pressure (BP) is measured using a sphygmomanometer by the supervising medical officer.
- Patients should be rested for 5 minutes before a reading is taken.
- BP should always be measured at rest, during the acclimatisation period on the cycle ergometer with no pedalling and whilst not on the mouthpiece, and again at maximal exertion (usually just after test termination). BP is also measured approximately every 2 minutes during exercise.

Rating of Perceived Exertion (RPE) / Modified BORG Scale

- A 0-10 scale is used to indicate the patient's perception of dyspnoea and leg fatigue (see Appendix B).
- It is important to outline that Rating of Perceived Exertion is a reflection of their "feeling of effort and exertion". Do not lead the patient's response. It is important that the rating of dyspnea describes an uncomfortable breathing sensation, and that 0=no uncomfortable breathing sensation and 10=most uncomfortable breathing sensation ever experienced.
- The RPE for dyspnoea and leg effort should be established before the test begins (baseline). Ratings are then taken throughout the test (approximately every minute) or once the test has ended. The end of test measurement should pertain to RPE at maximal exercise.

Exercise Flow-Volume Loops

- The plotting of flow-volume loops during exercise, measuring IC and EELV, provides a unique visual display of “ventilatory demand” versus “ventilatory capacity”, and can provide important information on the mechanisms of dyspnoea and exercise limitation during CPET^{1, 14}. The ability to record exercise flow-volume loops may not be available on all CPET systems.
- Subjects will be asked to periodically take a big breath in to total lung capacity (measuring the IC) and then continue breathing normally (see Appendix C for examples of exercise flow-volume loops).

4.7.2 Performing CPET and Data Collection

Medical Officer Evaluation

- The attending medical officer is required to examine the resting ECG prior to testing.
- The medical officer should be aware of the reason/s for the test and have the patient’s notes or an appropriate summary of the patient’s medical condition available for review.
- Any contraindications to exercise testing identified should be discussed with the supervising medical officer (and possibly the referring physician) and a decision made as to whether testing can safely proceed.
- Informed written consent must be obtained before the test can commence.
- The medical officer is required to monitor the exercise ECG continuously during the test and perform regular blood pressure measurements during and after exercise.
- The supervising medical officer is required to manage any adverse medical events during or immediately after the test, and should be present until the recovery data shows a return to pre-testing levels, particularly with regards to heart rate and blood pressure (typically at least 10 minutes post exercise).

Test Explanation and Equipment Familiarisation

- The testing protocol should be briefly outlined to the patient (suggested below):
- “This is an exercise test that requires a maximal effort. The more effort you put in, the more information we will obtain. We will be measuring your breathing through a mouthpiece. It is essential that your lips remain tightly sealed around the mouthpiece at all times during the test. The test will begin with a collection of resting measurements with no pedalling. You will then go into the exercise task and be asked to pedal at approximately 60 rpm (*the required speed may be ergometer-specific and manufacturer’s guidelines should be consulted*). Every minute the workload will increase with pedalling becoming more difficult until you won’t be able to continue”.
- “We expect that the test will take 8-12 minutes. It is usually only hard during the last few minutes when we collect the most important data. Throughout the test we want you to pedal between 50-70 rpm and ensure that you keep your lips tightly sealed on the mouthpiece. During the test we will be taking your blood pressure and monitoring your heart rhythm to make sure it is safe to keep exercising. When the test has finished we want you to ride for another 2-4 minutes at a very low workload to help your body recover from the exercise”.
- “If at any stage you feel any major discomfort such as strong chest pain, severe leg pain or nausea, let us know and we will stop the test. Otherwise, carry on pedalling until your legs or breathing prevents you from continuing. We will be asking you to indicate on a scale how short of breath you are and how tired your legs are”.

Baseline / Pre-Exercise Phase

- Subjects should be seated comfortably on the ergometer, ensuring the seat is at the correct height. The resting blood pressure should be measured, and then the noseclip placed on the patient's nose, and their mouth sealed tightly around the mouthpiece. 3 minutes of baseline data (normal breathing, no pedalling) is then collected.
- An optional 3 minute unloaded pedalling phase follows, depending on the ability of your system to conduct unloaded pedalling (0 watts).
- In the absence of 3 minutes of unloaded pedalling, a short warm-up phase should occur (~30 seconds), to allow the patient to pedal at the required speed before the exercise phase begins.

Exercise Phase

- Incremental vs. Ramp protocol:
 - An incremental protocol is most widely used, with workload increments increasing every minute of the exercise test until the subject has reached exhaustion, or until the supervising medical officer stops the test on medical grounds.
 - In the case of a first test, increments are calculated using the equations developed by Pretto et al¹⁵:
 - $\text{Increments (watts)} = 1.94 \text{ FEV}_1 + 0.21 \text{ TLCO} - 0.07 \text{ Age} + 1.94 \text{ Gender} + 4.12$
 - Or (if TLCO not available), $\text{Increments (watts)} = 3.05 \text{ FEV}_1 - 0.09 \text{ Age} + 2.44 \text{ Gender} + 6.18$
(FEV₁ is in litres, TLCO in ml/min/mmHg, Age in years and Gender = 1 for male, 0 for female)

If the subject has previously had a CPET performed, the same increment as the previous test should be used for ease of comparison.

The above equations are designed to enable the subject to achieve an exercise duration of 8-12 minutes, which has been shown to elicit optimal results^{16, 17}

 - Some systems will have the capability to run a ramp protocol where the workload is continuously increasing. The same overall workload should be used whether using a ramp or incremental protocol (i.e. if a 10 watt increment is calculated for a subject, the ramp should be set to increase 10 watts every minute but at a continuous rate, so at the end of 8 minutes the workload will be 80 watts).
 - Ramp protocols have been shown to possibly result in a higher peak workload in select subjects, but do not impact other physiological responses such as VO₂peak compared to incremental protocols.^{1, 18}
- The exercise phase continues until the subject has reached the point of exhaustion or until the medical officer stops the test on medical grounds. Termination of a CPET on medical grounds is at the discretion of the attending clinician should any termination criteria arise (see section 4.4.3. Indications for Exercise Termination). If the subject has stopped the test, they should be asked their reason for stopping (severe dyspnoea, leg fatigue, etc) and this should be recorded on the report.

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- Once in the recovery phase, the patient can come off the mouthpiece and remove the noseclip. The subject must continue to pedal slowly for several minutes (at a very small or no workload) to avoid the risk of hypovolemia, hypotension and syncope. Monitoring of the patient should continue for 5-10 minutes post exercise or until the heart rate, blood pressure and any exercise-induced symptoms have resolved to near pre-exercise values.
- Once the test has been completed, disconnect the patient from the ECG, blood pressure sphygmomanometer and pulse oximeter.
- Remove all ECG electrodes.
- Allow the patient to get dressed in private.

4.8. Interpretation

4.8.1 Reference Equations

- Each laboratory must select an appropriate set of reference values that best reflects the characteristics of the population tested and the equipment and methodology used.
- Reference values given by Jones et al¹⁹ and by Hansen et al²⁰ are the most widely used¹ (see Appendix D).
- Maximum VO_2 should also be referenced to body weight (in kilograms) in the report so that the impact of body size on exercise results is readily recognised²¹.

4.8.2 Interpretative strategies

- It is recommended in the ATS/ACCP statement¹ that the flowchart (depicted in Appendix E) which focuses on multiple measurements is used in the interpretation of CPET.

4.8.3 Identification of key variables and the determination of whether the results are normal or abnormal compared with appropriate normal reference values

- Key measurements and variables must be identified, starting with VO_2 , then HR, V_E and SpO_2 , and followed by other variables and exercise-limiting factors (cardiovascular, ventilatory, and peripheral).
- See Appendix F for a table of measurements taken during CPET and suggested criteria of normality for interpretation.
- See Appendix G for a table of additional measurements taken during CPET where a suggested criterion of normality for interpretation is not always applicable.

4.8.4 Presentation of the data

- It is recommended in the ATS/ACCP statement¹ that the data is presented in a 9-plot graph format, although the plots used may vary depending on the capabilities of the system, needs of the laboratory and what data is deemed of most importance by each individual laboratory.
- Please see Appendix H for examples of the 9-plot graph format.
- It is also recommended that resting and peak data for VO_2 (absolute and per kg), heart rate, ventilation, and oxygen saturation as well as peak work rate be presented in summary form with corresponding predicted peak values.

- It is important to understand how data is averaged or smoothed in individual CPET systems. The majority of modern, commercially available systems use breath by breath analysis (as opposed to a mixing chamber) to measure gas exchange parameters (VO_2 , VCO_2 , etc) and will average the breath by breath values to calculate reported values. Some variations in methodologies include averaging every 10, 20 or 30 seconds; averaging median values; linear regression; or a 7/5 breath smoothing algorithm. Each of these methods may lead to variations in values being reported for peak VO_2 , Work, VE , etc. There is a lack of evidence in the literature as to which method should be used, but it is the recommendation of this guideline that the last 30 seconds of breath by breath data be averaged for reporting of peak exercise values (depending on individual system limitations).

4.8.5 Distinction between physiologic and pathologic causes of exercise limitation¹

- In a normal healthy adult, there may be a slight anticipatory increase in heart rate, blood pressure and ventilation before the onset of exercise.
- Once contraction of locomotor muscles begins, there are both central and peripheral mechanisms governing the appropriate regulation of cardiopulmonary responses.
- VO_2 rises fairly linearly with work rate throughout progressive exercise because of an increase in cardiac output and increased oxygen extraction at the tissues.
- Ventilation rises early in exercise as a result of an increase in tidal volume and frequency of breathing, and linearly with VO_2 and VCO_2 until the approximate time when lactate begins to increase in arterial blood. At this point, commonly referred to as the 'anaerobic threshold', V_E and VCO_2 begin to increase out of proportion to VO_2 .
- There are several techniques that can be employed for detecting the anaerobic threshold. See Appendix I for a more thorough discussion of anaerobic threshold, the techniques for detecting it, and how it can be used in the interpretation of CPET.
- See Appendix J for a flow chart of abnormal patterns of response from CPET which are characteristic of disorders that cause dyspnoea.

4.8.6 Establishing patterns of exercise responses and limitations¹

- In a normal, sedentary individual, ventilation does not appear to be the limiting factor, because at maximal exercise there is significant ventilatory reserve.
- Pulmonary gas exchange does not appear to limit exercise because blood O_2 saturation and content are kept near baseline values.
- In healthy subjects, peak exercise is generally associated with heart rates close to the age predicted maximum chronotropic capacity of the heart, suggesting that cardiac output normally approaches its maximum capacity at peak exercise.
- See the table in Appendix K which depicts usual cardiopulmonary exercise response patterns.

4.8.7 Generating final report

- It is recommended that where feasible the medical officer supervising the CPET is also involved in the interpretation and reporting of the CPET.

4.8.8 Quality Control Procedures

Assessment of overall quality of the test, subject effort and reason(s) for exercise cessation¹

- Assessment of maximal patient effort:
 - The patient achieves predicted peak oxygen uptake and/or a plateau is observed.
 - Predicted maximal work rate is achieved.
 - Predicted maximal heart rate is achieved.
 - There is evidence of ventilatory limitation (peak exercise ventilation approaches or exceeds maximal ventilatory capacity).
 - RER values are greater than 1.15 indicating near maximal or maximal effort.

Quality control of equipment

- Pneumotachograph¹³:
 - Validation of any flow or volume device is essential for confidence in the ability of the device to measure accurately and reproducibly under test conditions.
 - Standards include a calibrated large volume syringe of 3 litres and various gas flow meters. These secondary standards should be calibrated against a spirometer before use.
 - If flow or volume signals are further processed by analogue or digital means, the results are subject to the response characteristics and calculation methods of these instruments as well.
 - Flow range: 0-12L/sec, full scale.
 - Volume accuracy: $\pm 3\%$ of reading.
- Analysers:
 - Gas analysers are checked for linearity within the range of the required values. This is achieved by analysing gases of known concentration of oxygen and carbon dioxide
 - If an analyser is non-linear, a calibration curve at several calibrations is drawn or alternatively a continuous curve is developed.
 - Calibration is performed with gases of a known concentration. The analyser is warmed up for sufficient time to ensure no electrical drift.
 - An identical sampling arrangement to that used during testing is used.
 - It is convenient to use dry room air as one calibration point, assuming an oxygen concentration of 20.95% and carbon dioxide of 0.04%.
 - The other gases used are 4-5% CO₂, 15-17% O₂, N₂ balance.
 - Thermal conductivity: CO₂ analyser range: 0 – 10 Vol% CO₂.
 - Galvanic fuel cell: O₂ analyser range: 0 – 25 Vol% O₂.
- Ergometer bike:
 - Calibration of the bike is highly desirable, prior to initial use and periodically thereafter as part of annual preventative maintenance or as part of a service contract.
 - Commercially available or specially built devices that generate known amounts of power can act as standards for calibration and verification.
 - Additionally, because oxygen uptake maintains a very constant relationship to work rate (~10.3ml/min/watt), regular biological control measurements in healthy subjects will allow validation of this VO₂-Work relationship and provide an indirect measure of both VO₂ and work (ergometer) accuracy.

5. Review

This Guideline is due for review on: 16/02/2017

Date of Last Review: N/A

Supersedes: Nil

6. Business Area Contact

Statewide Respiratory Clinical Network, Clinical Access and Redesign Unit, Health Systems Innovation Branch, Health Service and Clinical Innovation Division.

7. Definitions of terms used in the guideline and supporting documents¹

Term	Definition / Explanation / Details
AT (anaerobic threshold)	The oxygen consumption above which aerobic energy consumption is supplemented by anaerobic metabolism leading to increased blood lactate levels during exercise ²⁴ .
B by B (breath by breath)	Value of a particular physiologic variable measured over one breath (entire respiratory cycle).
FEV₁ (forced expiratory volume in one second)	Volume of gas exhaled from the lungs during the first second of a forced expiratory manoeuvre (FVC) expressed in litres and reported at BTPS.
HR (heart rate)	Number of heart beats per minute.
HRR (heart rate reserve)	Difference between the highest heart rate attained during a maximal exercise test and the maximal value predicted for that subject. Expressed in beats per minute (bpm).
MVV (maximal voluntary ventilation)	Maximal volume of air that can be breathed per minute by a subject.
RER (respiratory exchange ratio)	Ratio of CO ₂ output to O ₂ uptake (measured at the mouth).
RQ (respiratory quotient)	Ratio of the rate of CO ₂ production to oxygen consumption.
SpO₂ (arterial oxygen saturation as indicated by pulse oximetry)	Noninvasive estimation of arterial haemoglobin oxygen saturation, using a device that utilises the combined principles of spectrophotometry and pulse plethysmography. The probe (sensor) can be used on the ear lobe or fingertip.
VCO₂ (carbon dioxide output)	Amount of CO ₂ exhaled from the body per unit of time, expressed in millilitres per minute or litres per minute and reported at STPD.
V_D (physiologic dead space)	Notional volume of inspired gas that does not reach a gas-exchanging unit. The physiologic dead space is therefore the sum of the anatomic dead space and the alveolar dead space. It is expressed in units of millilitres or litres and reported at BTPS.
V_E (minute ventilation)	Volume of expired air exhaled from the lungs in 1 minute. This is conventionally expressed in units of litres per minute and reported at BTPS

8. Approval and Implementation

Consultation:

Key stakeholders (position and business area) who reviewed this version are:

- Statewide Respiratory Clinical Network (SRCN) Cardiopulmonary Exercise Testing sub-group members: Mark Davis (Respiratory and Sleep Scientist, Royal Brisbane and Women’s Hospital), Lauren Dunn (Respiratory Scientist, The Prince Charles Hospital), Sjane Stevens (Respiratory Scientist, Prince Charles Hospital), Jarrod Warner (Respiratory Scientist, Princess Alexandra Hospital), Joanne Wex (Manager, Clinical Measurements Department, Rockhampton Hospital) and Jessica Wilson (Respiratory Scientist, Robina Hospital).
- SRCN Lung Function Testing work group members: Michael Brown (Chair, Lung Function Testing work group and Director, Sleep and Respiratory Sciences, Royal Brisbane and Women’s Hospital), Andrew Coates (Chief Respiratory Scientist, Lung Function Lab, Mater Health Services), Brenton Eckert (Scientific Director, Respiratory Lab, Princess Alexandra Hospital) and Irene Schneider (Clinical Educator and Respiratory Scientist, The Prince Charles Hospital).
- Queensland Medical and Scientific Respiratory Laboratory Directors: Michael Brown (Director, Sleep and Respiratory Sciences, Royal Brisbane and Women’s Hospital), Andrew Coates (Chief Respiratory Scientist, Lung Function Lab, Mater Health Services), Brenton Eckert (Scientific Director, Respiratory Lab, Princess Alexandra Hospital), Dr Craig Hukins (Director, Department of Respiratory and Sleep Medicine, Princess Alexandra Hospital), Dr Khoa Tran (Medical Director, Respiratory Laboratory, Logan Hospital) and Associate Professor Paul Zimmerman (Director, Department of Thoracic Medicine, The Prince Charles Hospital).
- Dr Luke Garske (Respiratory Physician, Princess Alexandra Hospital, previous chair of the SRCN Cardiopulmonary Exercise Testing sub-group).

Guideline Custodian:

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Approving Officer:

Dr Bill Kingswell, A/Deputy Director-General, Health Service and Clinical Innovation Division

Approval date: 21 April 2015

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Version Control

Version	Date	Prepared by	Comments
1.0	21/04/2015	CPET Work Group, Statewide Respiratory Clinical Network	Endorsed by Statewide Respiratory Clinical Network Steering Committee

9. References

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10. Appendices

Appendix A: Example CPET Worksheet

Cardiopulmonary Exercise Test Worksheet

Date:..... UR:.....
Patient:..... Height (cm):..... Wt (kg):.....
Consultant:..... Scientist:.....
Supervising Physician:.....
Medications:.....
.....
Informed Consent: Yes No

Exercise Workload Protocol
Increment:.....Watts/minute (ref: Preto)
Maximum predicted:.....Watts

Baseline Data
Heart Rate:.....bpm SpO₂:.....% BP:.....

Reasons for Stopping:.....
Comments on testing:

BORG Scores
Start Breathing / 10 Legs /10
End

ECG Comment:
.....
.....
.....

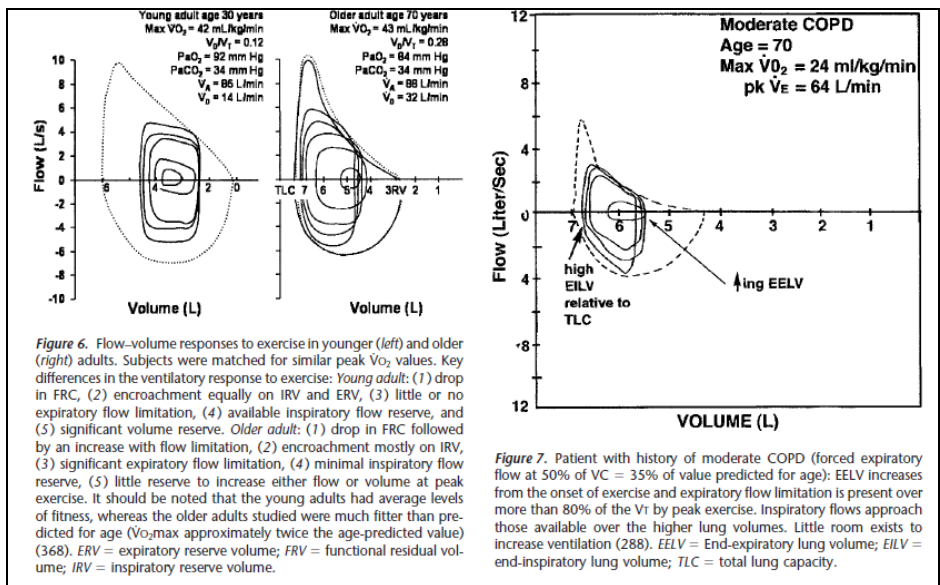
General Comments:.....
.....
.....

Supervising Physician's Signature:

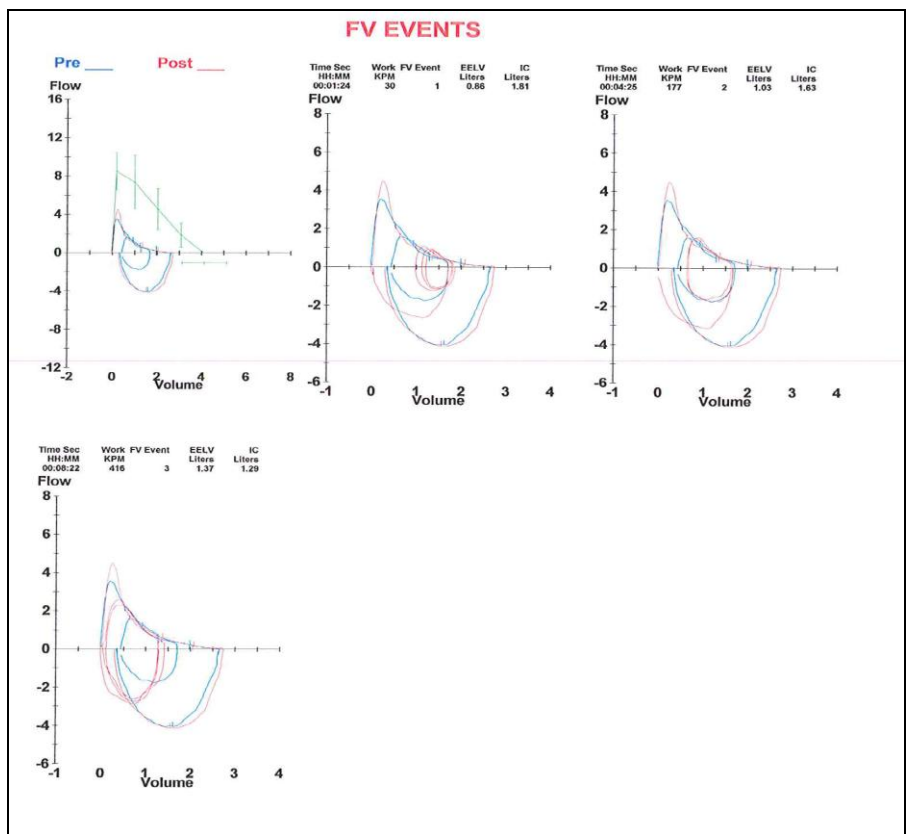
Appendix B: Modified Borg Perceived Exertion Scale

Number	Verbal Expression
0	Nothing at all
0.5	Very, very light (just noticeable)
1	Very light
2	Light
3	Moderate
4	Somewhat severe
5	Severe
6	
7	Very severe
8	
9	
10	Very, very severe

Appendix C: Example Exercise Flow-Volume Loops



Example 1¹



Example 2: Subject with COPD. Note the increase in EELV and decrease in IC during the CPET.

Appendix D: Selected Reference Equations for Maximal Incremental CPET (tables adapted from Reference 1)

Jones et al., 1985¹⁹:

Variable	Equation	SEE
Work rate, <i>kpm/min</i>	$20.4(\text{Ht}) - 8.74(\text{Age}) - 288(\text{Sex}) - 1909$	216
VO ₂ , <i>L/min</i>	$0.046(\text{Ht}) - 0.021(\text{Age}) - 0.62(\text{Sex}) - 4.31$	0.458
VO ₂ , <i>ml/min/kg</i>	Male: $55 - 0.44(\text{Age})$ Female: $43 - 0.36(\text{Age})$	6.5 6.6
Heart-rate, <i>beats/min</i>	$202 - 0.72(\text{Age})$	10.3
O ₂ pulse, <i>ml/beat</i>	$0.28(\text{Ht}) - 3.3(\text{Sex}) - 26.7$	2.8
Ventilation, <i>L/min</i>	$26.3(\text{VC}) - 34$	23.1
VO ₂ at anaerobic threshold, <i>L/min</i> :	$0.024(\text{Ht}) - 0.0074(\text{Age}) - 2.43$	0.316

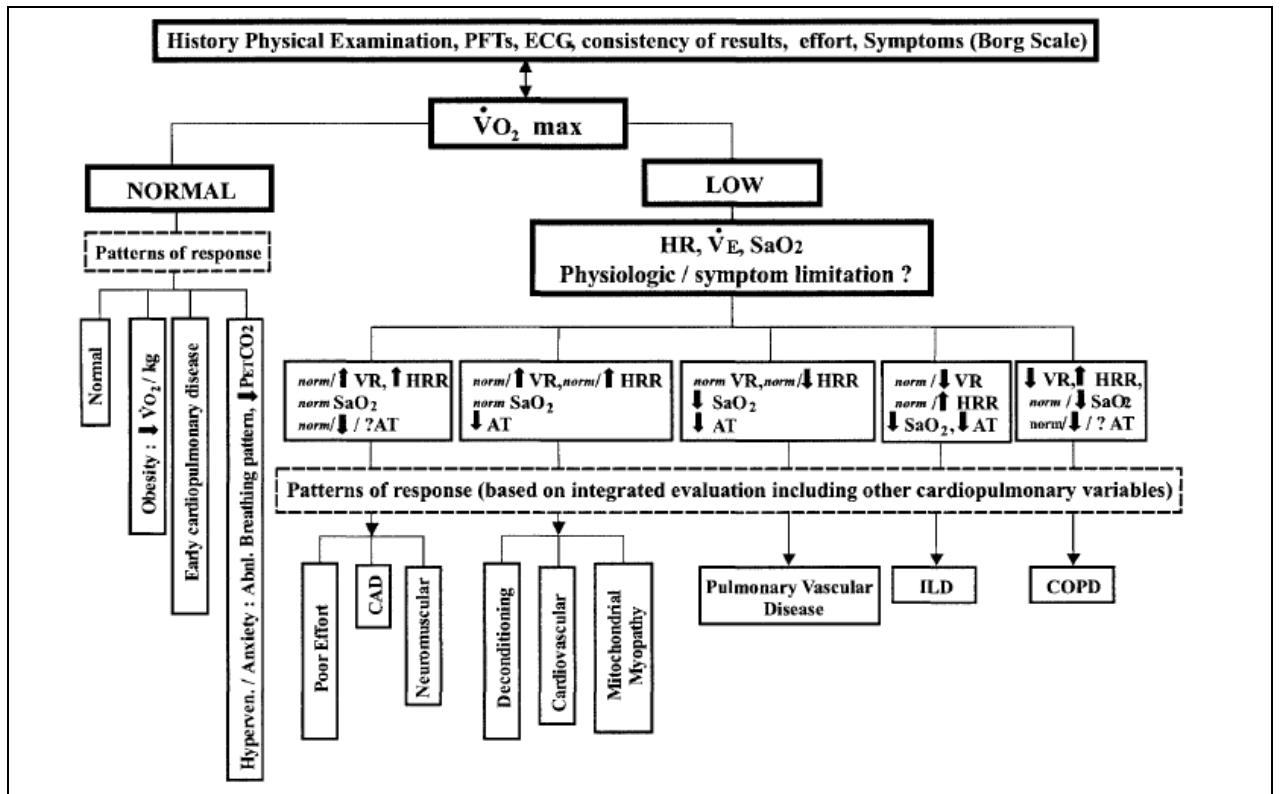
Hansen et al., 1984²⁰:

Variable	Equation
VO ₂ , <i>L/min</i>	Male: $[\text{Wt} \times \{50.75 - 0.372(\text{Age})\}] / 1000$ Female: $[(\text{Wt} + 43) \times \{22.78 - 0.17(\text{Age})\}] / 1000$
Heart-rate, <i>beats/min</i>	$210 - 0.65(\text{Age})$
O ₂ pulse, <i>ml/beat</i>	Predicted VO ₂ max / predicted heart-rate max
V _E /MVV, %	~72 +/- 15
VO ₂ at anaerobic threshold, <i>L/min</i> :	> 40% VO ₂ predicted

Predicted weight (men) = 0.79 x Ht – 60.7. Predicted weight (women) = 0.65 x Ht – 42.8. When actual weight > predicted, the predicted weight should be used in the Hansen equations.

Ht = height in cm; Wt = weight in kg; Age = age in years; Sex, male = 0, female = 1; VC = measured vital capacity in L; SEE = standard error of estimate

Appendix E: Interpretation of peak CPET results^{1, 22}



Appendix F: Measurements during CPET and the suggested criteria of normality for interpretation (adapted from reference 1)

Measurements	Variables	Criteria of Normality
Metabolic Gas Exchange	VO ₂ max (maximum oxygen uptake)	>84% predicted
	AT(anaerobic threshold)	>40% VO ₂ max predicted; wide range of normal (40-80%)
Cardiovascular	HR (heart rate)	HRmax* >90% age predicted
	HRR (heart rate reserve)	HRR <15 beats/min
	O ₂ pulse (VO ₂ /HR)	>80%
	BP (blood pressure)	<220/90
	f _R (respiratory frequency)	<60 breaths/min
	VR (ventilatory reserve)	MVV-V _E max >11L or V _E max/MVV x 100 <85% Wide normal range: 72 ± 15%
Pulmonary Gas Exchange	V _E /VCO ₂ (ventilation per unit of carbon dioxide production)	<34

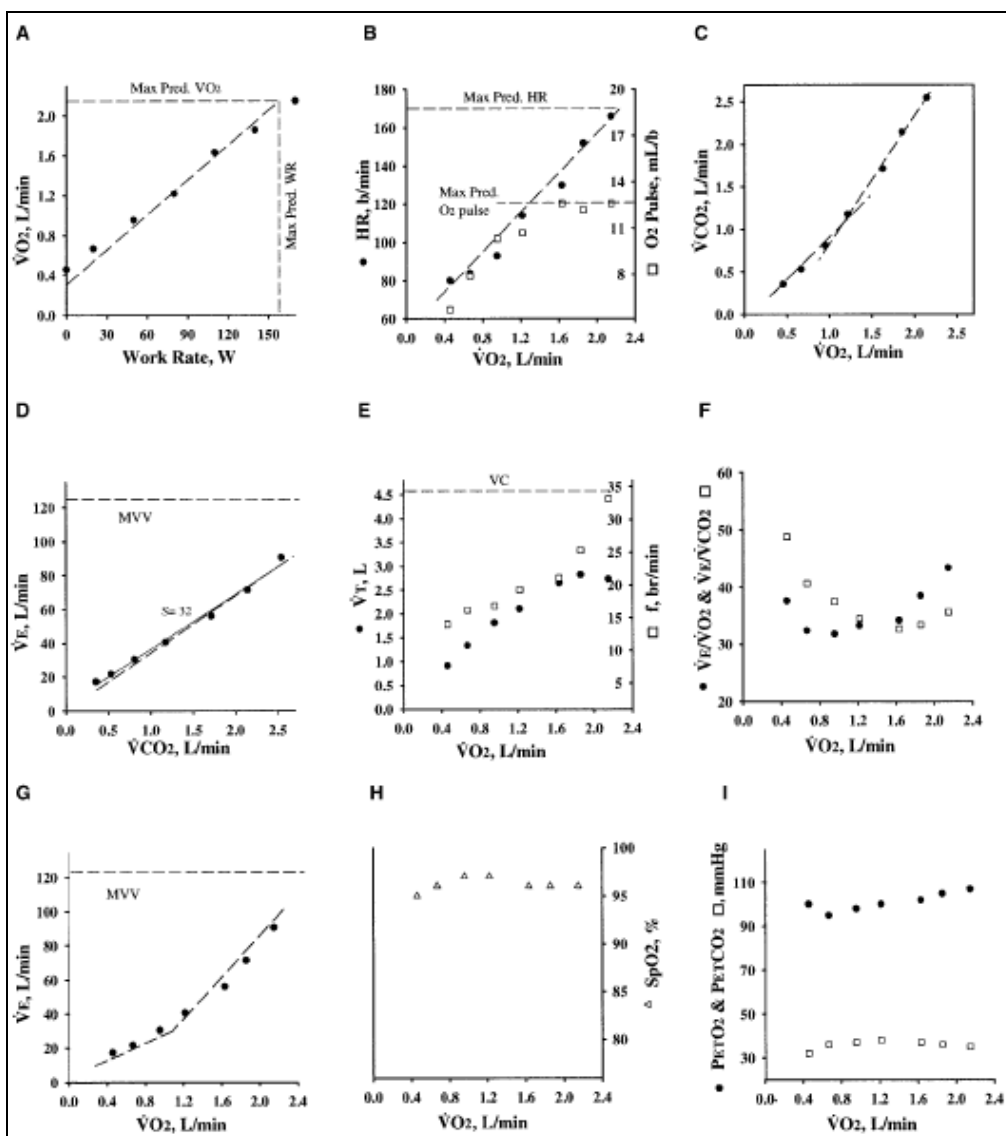
*Maximum heart rate calculation depends on reference values chosen.

*Appendix G: Additional measurements taken during CPET
(adapted from reference 1)*

Measurements	Variables
<i>External Work</i>	WR (work rate)
<i>Metabolic Gas Exchange</i>	VCO ₂ (carbon dioxide output)
	RER (respiratory exchange ratio) or RQ (respiratory quotient)
<i>Cardiovascular</i>	ECG (electrocardiogram)
<i>Ventilatory</i>	V _E (minute ventilation)
	V _T (tidal volume)
	Respiratory rate
<i>Pulmonary Gas Exchange</i>	SpO ₂ (arterial oxygen saturation as measured by pulse oximetry)
	V _E /VO ₂ (ventilatory equivalent for oxygen uptake)
<i>Symptoms</i>	Dyspnoea
	Fatigue
	Chest Pain

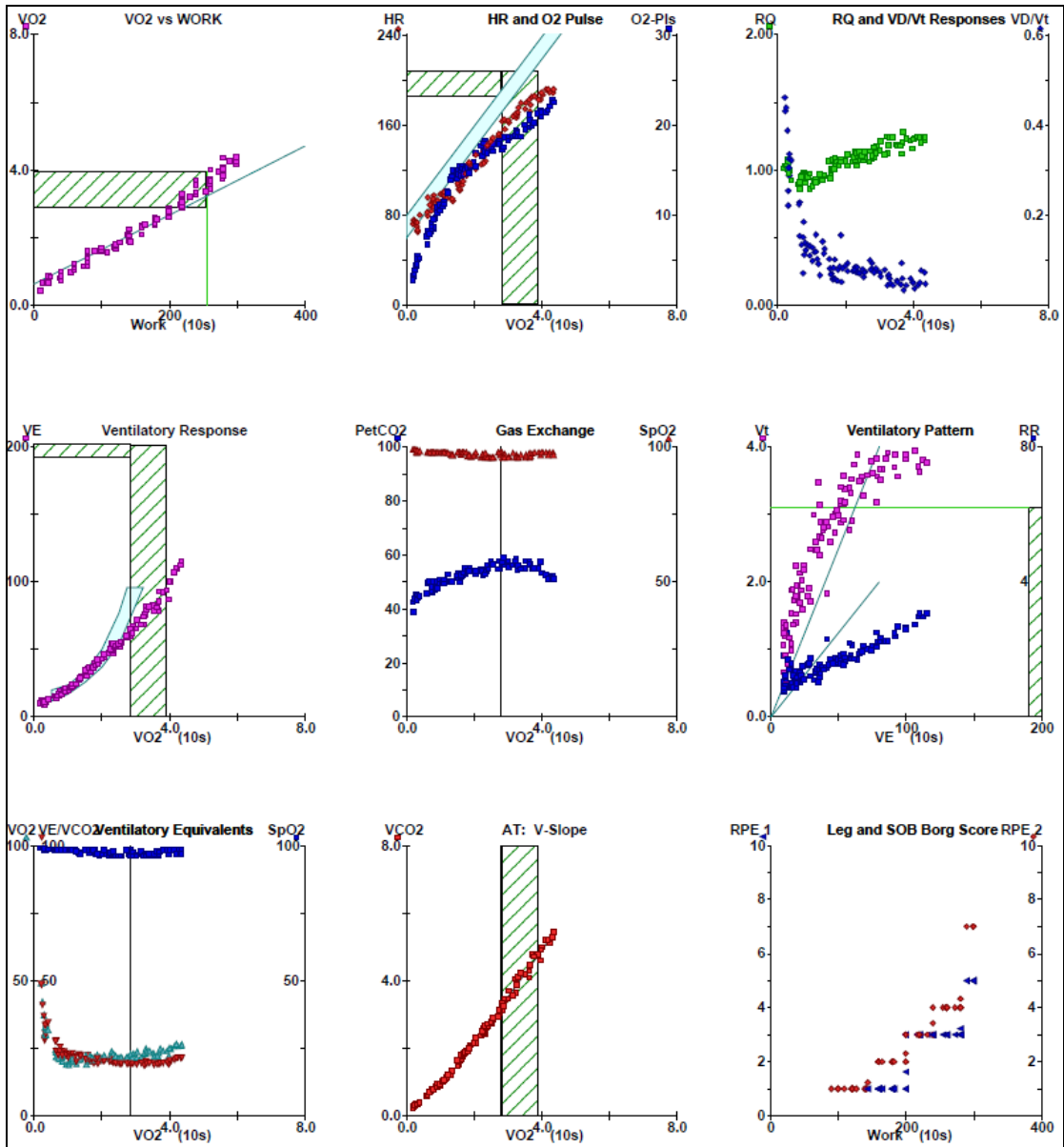
Appendix H: 9 plot graph examples (normal responses to exercise)

Example 1¹



- A. Oxygen uptake ($\dot{V}O_2$) versus work rate (W)
- B. Heart rate (HR) and O_2 pulse versus $\dot{V}O_2$
- C. Indirect determination of the anaerobic threshold (AT) using the modified V slope method, in which carbon dioxide production ($\dot{V}CO_2$) is plotted versus $\dot{V}O_2$
- D. Minute ventilation (\dot{V}_E) versus carbon dioxide output ($\dot{V}CO_2$)
- E. Tidal volume (V_T) and respiratory frequency (f_R) versus $\dot{V}O_2$
- F. Ventilatory equivalent for O_2 ($\dot{V}_E/\dot{V}O_2$), ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$) versus $\dot{V}O_2$
- G. Minute ventilation (\dot{V}_E) versus $\dot{V}O_2$
- H. Pulse oximetry (SpO_2) versus $\dot{V}O_2$
- I. End-tidal pressure for O_2 ($P_{ET}O_2$) and end-tidal pressure for CO_2 ($P_{ET}CO_2$) versus $\dot{V}O_2$

Example 2 (axes marked appropriately)



Appendix I: Anaerobic threshold

- The anaerobic threshold (AT) is defined as the oxygen consumption above which aerobic energy consumption is supplemented by anaerobic metabolism leading to increased blood lactate levels during exercise²⁴.
- AT can be clinically useful when determining a patient's suitability for surgery²⁵. Accurate determination is important to ensure appropriate risk assessment and clinical decision making.
- Large inter-observer variation exists when detecting AT using a non-invasive method^{26, 27}. The reliability of such methods is sceptical due to the subjective nature of determining AT (i.e. using the V-Slope method, one can intentionally choose the ranges of drawing regression lines). Furthermore, poor exercise protocol selection and the experience of the interpreting scientist can add to the variation and subjectivity of an accurate AT²⁰. For these reasons, it is recommended AT remain undetermined unless otherwise specified from the requesting physician, and even then an "AT indeterminable" statement is recommended unless there is a clear, indisputable AT.
- If AT is essential to the interpretation of a CPET, it is recommended scientists utilise the experience and opinion of senior peers to reduce AT measurement error.
- The AT can be calculated via the Ventilatory Equivalents (Figure 1), and V-Slope method (Figure 2) using contemporary CPET software. It is recommended the Ventilatory Equivalents method be primarily utilised²⁸. Reasons include:
 - It has the highest correlation with AT determined from blood lactate.
 - It has the highest test-retest correlation.
 - V_E/VO_2 can easily be determined from standard ventilatory and gas exchange measurements.
 - V_E/VO_2 is triphasic that quantitatively allows the scientist to have more confidence in the determination of AT.
 - The dual criterion utilising V_E/VCO_2 provides a more specific detection of the AT.
- Clinical CPET typically uses two, non-invasive, methods to determine AT.
 - Ventilatory Equivalents Method (Figure 1)
 - When V_E/VO_2 increases without a simultaneous increase in V_E/VCO_2 , this is a specific gas exchange demonstration that the AT has been reached.

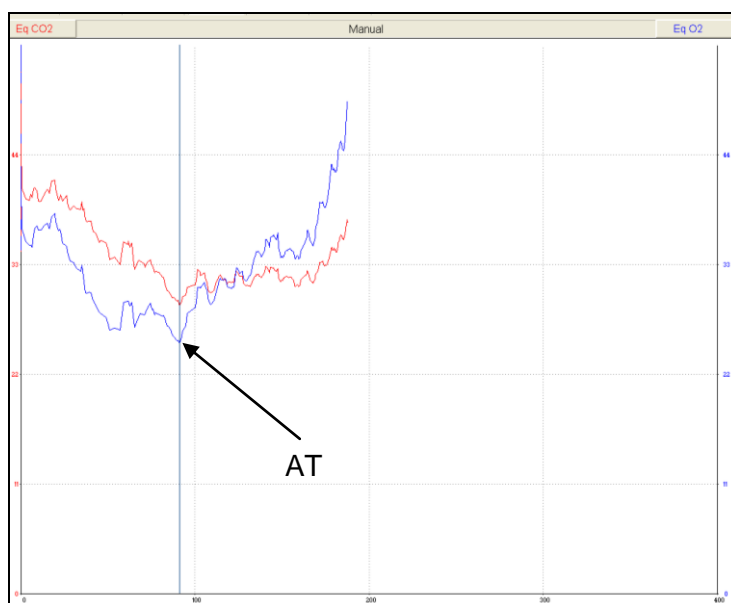


Figure 1: AT determined by the Ventilatory Equivalents Method

- V-Slope Method (Figure 2)
 - Net increase in lactate accumulation produces an acidosis, VCO_2 accelerates relative to VO_2
 - Relationship of two slopes ($S1$ and $S2$)
 - The intercept of the two slopes is the AT measured by gas exchange

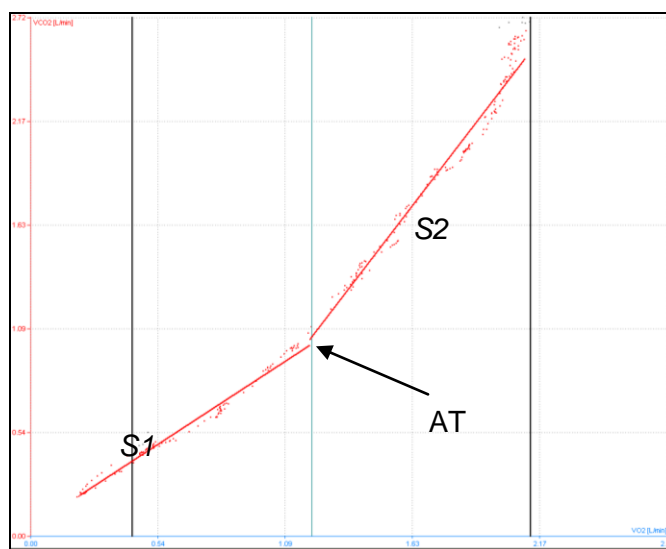
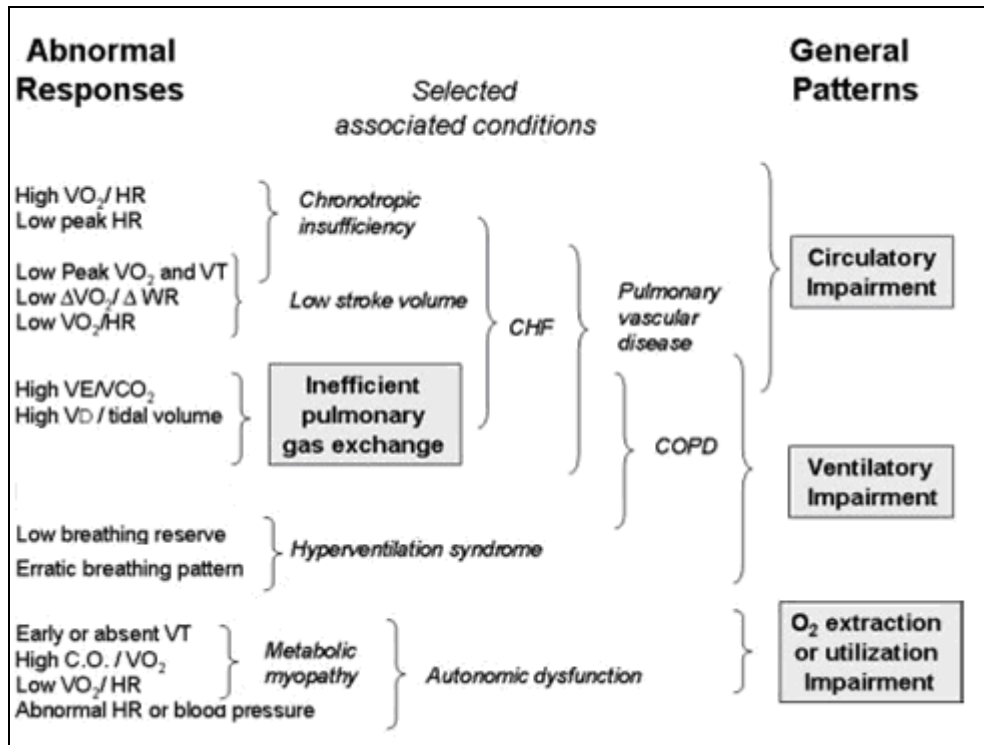


Figure 2: AT determined by the V-Slope Method

Appendix J: Abnormal patterns of response from CPET, characteristic of disorders that cause dyspnoea (adapted from reference 23)



Appendix K: Usual cardiopulmonary exercise response patterns¹

Measurement	Heart Failure	COPD	ILD	Pulmonary Vascular Disease	Obesity	Deconditioned
$\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$	Decreased	Decreased	Decreased	Decreased	Decreased for actual, normal for ideal weight	Decreased
Anaerobic threshold	Decreased	Normal/decreased/indeterminate	Normal or decreased	Decreased	Normal	Normal or decreased
Peak HR	Variable, usually normal in mild	Decreased, normal in mild	Decreased	Normal/slightly decreased	Normal/slightly decreased	Normal/slightly decreased
O_2 pulse	Decreased	Normal or decreased	Normal or decreased	Decreased	Normal	Decreased
$(\dot{V}_E/MVV) \times 100$	Normal or decreased	Increased	Normal or increased	Normal	Normal or increased	Normal
$\dot{V}_E/\dot{V}CO_2$ (at AT)	Increased	Increased	Increased	Increased	Normal	Normal
V_D/V_T	Increased	Increased	Increased	Increased	Normal	Normal
P_{aO_2}	Normal	Variable	Decreased	Decreased	Normal/may increase	Normal
$P(A-a)O_2$	Usually normal	Variable, usually increased	Increased	Increased	May decrease	Normal