BASES Physiological Exercise Testing Guidelines: CVD

Dr Victoria S. Sprung, Professor John P. Buckley & Dr David L. Oxborough

INTRODUCTION

Cardiovascular disease (CVD) provides one of the biggest challenges to exercise and health professionals in the United Kingdom (UK), and Worldwide. This is primarily due to the scale of the problem as well as the diversity and complexity of these diseases. It is well known that CVD is the most common pathology in 'Westernised' societies. The British Heart Foundation data compendium, published in April 2020, detailed that 7.6 million people live with CVD in the UK. In terms of mortality rate, CVD accounted for ~163,000 deaths in the UK which represented 27% of all deaths and ~43,000 of which were deemed premature (recorded in individuals under 75 years of age) in 2019 (British Heart Foundation, 2020). Further, CVD accounts for one third of deaths Worldwide. Coronary artery disease (CAD) accounts for the greatest proportion of CVD related deaths, and risk factors including hypertension, cigarette smoking, diabetes mellitus or glucose intolerance, hypercholesterolaemia, and obesity are the top six causes of death globally (Wong, 2014). CVD constitutes a huge medical burden to the National Health Service (NHS) as they are often progressive and impose a life-long burden of intervention and treatment that require the investment of time, labour, drug therapy and other broader cost implications. The most prominent and greatest amount of treatment in CVD is linked to acquired atheromatic diseases leading to ischaemic conditions and infarctions of the myocardium, or the brain. Electrical conductance disorders (e.g. arrhythmias) and myocardial dysfunction (e.g. ventricular heart failure) often transpire from these.

The umbrella term of CVD is an oversimplification of an exceptionally diverse set of pathologies. It should be acknowledged that any disease of the central or peripheral circulatory system is covered in the collective term "CVD". These include congenital, inherited, and acquired diseases which when broadly categorised form the three main groups of CVD.

Congenital, inherited and acquired heart disease

The term 'congenital' refers to an inborn (existing at birth) defect affecting the heart and proximal blood vessels. Some of the more common congenital cardiovascular defects include pulmonary stenosis, septal defects and aortic coarctation. Congenital cardiovascular defects are present in about 1% of live births and represent the most common congenital malformations in new-borns. The majority of congenital cardiovascular diseases obstruct blood flow in the heart or proximal vessels, or cause an abnormal pattern of blood flow through the heart. The natural history of congenital cardiovascular defects is incompletely understood. Amongst the possible candidates for causative factors are heredity, viral infections (e.g. rubella), certain conditions affecting multiple organs (e.g. Down's syndrome), some prescription drugs and over-the-counter medicines, as well as alcohol and recreational drugs.

The term 'inherited' refers to diseases that have a genetic origin and are often familial (diseases that run in families). Inherited heart diseases are disorders of the DNA code (known as 'mutations') of specific genes, and examples include cardiomyopathies such as hypertrophic cardiomyopathy and dilated cardiomyopathy. The process of inheritance depends upon whether the gene is dominant or recessive and the number of affected siblings in a family will depend upon the penetrance and the

chromosome within which the abnormal gene resides. Although an individual may be a carrier (ie. positive genotype), they may not always express a positive phenotype.

Acquired heart disease covers a broad spectrum of CVD that can be attributable to lifestyle and environment (although some genetic component may be present) and develop over a more prolonged period. Specifically, these diseases, such as CAD, valve disease, hypertensive remodelling and heart failure are not present at birth and normally manifest themselves in mid-to later-life. We now possess a degree of knowledge related to the development of acquired heart disease as well as some of the key risk factors including hypertension, hyperlipidaemia, physical inactivity, obesity, and smoking. Due to their prevalence and impact upon lifestyle, socioeconomics and morbidity/mortality statistics, acquired CVD are at the core of the health-related roles now fulfilled by appropriately trained sport and exercise scientists.

EXERCISE TESTING IN CARDIAC DISORDERS

One increasingly common intervention to aid prevention and improve outcomes of CVD is physical activity (Thomas, Baker and Davies, 2003; Cobiac and Scarborough, 2017). A structured approach when attempting to increase levels of physical activity generally begins with the assessment of aspects of cardiovascular health (structure and function; covered in Chapter XX) as well as the determination of an individual's cardiorespiratory fitness; normally performed via maximal and/or symptom limited incremental treadmill or cycle ergometry. In rehabilitative practice however, for pragmatic and access purposes, submaximal field-based shuttle walking/running, cycling and step tests are used (see Chapter XX for basic principles). The understanding of cardiovascular health and physical performance capabilities are required to determine prognosis, risk stratification and functional capability measures, from which guidance for treatment and surgery, physical activity and exercise prescription can be made. This chapter cannot cover all tests associated with CVD patients but a range of exercise tests that have been employed to assess (or estimate) cardiovascular performance capacity will be reviewed. In this section we wish to move forward from just a standard graded exercise tolerance test (Corra et al., 2004) and detail other methods of assessment of cardiovascular performance capacity that may include tests that are sub-maximal in nature and/or may be functionally relevant (Olsson et al., 2005). When selecting the mode of exercise test utilised, the test purpose and patient preference should also be considered (Fletcher et al., 2013).

Exercise testing in congenital, inherited and acquired heart disease

Careful consideration regarding the nature of the underlying CVD is crucial in the safe management of exercise testing, and indeed exercise prescription, in all patients. Specific concerns in congenital and inherited heart disease are related to the variety of structural and/or functional alterations of the heart or proximal vessels and an abnormal cardiovascular response to exercise is expected. The abnormalities associated with congenital and inherited CVD, as well as the issues related to acquired CVD, affect (i) the electrical conduction through the heart; (ii) the functional capacity of the heart; and, (iii) the function of the peripheral vasculature. As noted in the next section, respiratory responses to exertion can provide important prognostic and diagnostic information in relation to cardiac function. In all patients with cardiac disease the impact of drug therapy on exercise tolerance and physiological response to exercise should also be considered; particularly those associated with chronotropic and inotropic function. Further, exercise stress testing in extremely sedentary patients may not yield maximum values for various physiological parameters. The use of gas exchange

response during testing in these patients may be a valuable addition in the diagnosis of the condition, evaluation of exercise capacity and subsequent prescription of exercise (Whyte et al., 1999; Lainchbury and Richards, 2002). Contraindications to exercise (Table 1) should be carefully evaluated and, given the increased potential for adverse outcome, particularly during maximal exercise testing, appropriate steps should be taken to avoid incidents including modification of protocols and availability of appropriately trained individuals. Due to the range of observed abnormalities, integrated cardiopulmonary stress testing including simultaneous 12-Lead ECG, blood pressure and gas exchange during and post-exercise (for a minimum of 10 minutes) is recommended in most cases, particularly for hospital-based clinical assessment (Myers et al., 1998; Myers et al., 2000).

Absolute contraindications	Relative contraindications
▪ Acute myocardial infarction (3–5 days) ▪ Unstable angina ▪ Uncontrolled/symptomatic arrhythmia ▪ Acute right-sided heart failure ▪ Uncontrolled heart failure ▪ Syncope ▪ Active endocarditis ▪ Acute myocarditis or pericarditis ▪ Symptomatic severe aortic stenosis ▪ Suspected dissecting/leaking aortic aneurysm ▪ Arterial desaturation at rest (<85%)	▪ Untreated left main stem coronary stenosis ▪ Asymptomatic severe aortic stenosis ▪ Severe untreated arterial hypertension at rest (>200mmHg [systolic], >120mmHg [diastolic]) ▪ Tachyarrhythmias or bradyarrhythmias ▪ Hypertrophic cardiomyopathy ▪ Significant pulmonary hypertension ▪ Untreated thrombosis of the lower extremity ▪ Acute symptomatic pulmonary embolus (2 weeks) ▪ Abdominal aortic aneurysm >8.0 cm

Table 1. Absolute and relative contraindications for CPET (adapted from American Thoracic Society(ATS)/American College of Chest Physicians (ACCP) (2003), Perioperative Exercise Testing and Training Society (POETTS) (2018) and American Heart Association (AHA) CPET guidelines (2010)). Patients with absolute contraindications should be discussed with an appropriate clinician in terms of risks/benefits of testing. Patients with relative contraindications should receive direct supervision from a physician.

Cardiopulmonary Exercise Test

The ideal exercise test employed in the clinical environment for patients with, or suspected of having, CVD is the integrated cardiopulmonary exercise test (CPET), however not all centres have this capacity. The American College of Sports Medicine (ACSM) describes the value of this assessment in terms of determining the presence of significant heart disease, and specifically CAD (2020). However, practitioners should exercise caution if utilising this assessment for diagnostic purposes, where imaging is generally recommended. In patients with known heart disease, such tests are useful for assessing functional tolerance (e.g. anginal thresholds), progress of rehabilitation, influence of drug administration, and other important issues. To this end, CPET is complimentary to define prognosis (Kokkinos et al., 2008; Kodama et al., 2009), determine risk stratification (Williams et al., 2004), and estimate functional capabilities of patients, which enables objective development of physical activity programmes. It is normal for the test to be treadmill-based, for the greatest cardiovascular work, and be continuous with exercise intensity progression achieved by staged changes in speed, incline, or both. Other clinical laboratory-based tests may use stepping or cycling protocols, but the treadmill test remains the 'gold standard'.

Generally speaking, stepwise protocols for CPET are most commonly used in CVD patients. CPET protocols with large stage increments in energy requirements display a weaker relationship between

peak oxygen consumption ($\dot{V}O_{2peak}$) and work rate. The Bruce/modified Bruce (1971) and individualised ramp protocols, which involve only modest increases in energy requirements per stage, are therefore recommended (Table 2). Patients should take their medications as usual, with the exception of beta blockers (avoided 24h prior to the assessment), and are encouraged to exercise until volitional fatigue in the absence of symptoms or other indicators of ischaemia. The use of handrails during the exercise test is discouraged. Results are expressed relative to body weight (ml/kg/min). Peak exercise time is recorded in minutes. Peak oxygen consumption is calculated as the highest consecutive 15 second period of gas exchange data occurring in the last minute before volitional exhaustion. Physiological criteria for assessment of $\dot{V}O_{2peak}$ included a levelling of $\dot{V}O_{2peak}$ and/or a respiratory exchange ratio of ≥1.15 combined with a maximal heart rate at least 90% of the age predicted maximal estimation (220-age) (ACSM, 2017).

Stage	Speed (mph)	Grade (%)	Duration (min)
1	1.7	0	3
2	1.7	5	3
3	1.7	10	3
4	2.5	12	3
5	3.4	14	3
6	4.2	15	3
7	5.0	15	3

Table 2. Stepwise increments of the modified Bruce Protocol (Reed et al., 2019).

Alternative outcome measures of a Cardiopulmonary Stress Test

In recent decades, other measures from an exercise test have been associated with prognosis, such as chronotropic response (Cole et al., 1999; Morshedi-Meibodi et al., 2002), oxygen uptake efficiency (Das et al., 2020), and $\dot{V}E/\dot{V}CO_2$ (Sayegh et al., 2020). These measures in addition to a simple $\dot{V}O_{2peak}$ are invaluable, especially in clinical practice where patients rarely achieve a true maximum.

Assessment of Functional Capacity

There are now several valid and reliable exercise test alternatives to a maximal treadmill test that may be used, with appropriate considerations for the patient and the disease, in a broader range of exercise settings. Tests of exercise capacity or tolerance are often conducted outside of the clinical laboratory (e.g. phase III and IV cardiac rehabilitation in gyms/exercise physiology laboratories) and thus come more within the direct remit of sport and exercise scientists. Over the last two decades, significant interest has arisen in tests of functional capacity that more closely reflect activities of habitual daily lifestyle (Arena et al., 2007). Most interest has been focussed on a variety of walking tests and these have been used to assess functional capacity or to predict clinical outcomes/events (Girish et al., 2001), including protocols such as walks for time, walks for distance, and shuttle walks.

Walking tests

The incremental shuttle walk test (ISWT) is a maximal test that closely correlates with laboratory generated data (Singh et al., 1994). The test was initially developed with patients who had respiratory disease (Singh et al., 1992), but has more recently been used in a variety of CVD populations including stroke (Wittink et al., 2020), heart failure (Polgar et al., 2020), and CAD (Gayda et al., 2003). The ISWT has been determined to be safe and reproducible in the assessment of patients engaged in cardiac

rehabilitation programmes (Jolly et al., 2008). In heart failure patients, a shuttle walk test accurately predicted event-free survival at one year (Morales, Montemayor and Martinez, 2000) as well as predicting $\dot{V}O_{2peak}$ (Morales et al., 1999). Furthermore, research from Gayda and colleagues (2003) reported that using the validated 20-m shuttle walk test in patients with CAD yielded a maximal walking pace that was not dissimilar to maximal treadmill speed. More recent research evidence points to the utility of walking-based exercise tests in which patients self-select their speed and thus are more reflective of daily living, such as the 6-min walk test (Holland et al., 2014) whereby patients given standardised instruction to walk as far as possible in 6 min along a flat corridor.

Accurate heart rate (HR) measurement is vital during testing. Although this can be obtained via palpation, the experience/technique of the practitioner acutely impacts the accuracy of this measurement; it is recommended therefore that an ECG or validated HR monitor be utilised.

As far back as 1996, researchers have identified that the shuttle walk is easy to administer, requires little equipment, and produces a symptom-limited maximal performance (Payne and Skehan, 1996). Green et al. (2001) provided evidence to support the reliability of the shuttle walk test as well as describing a closer relationship between treadmill $\dot{V}O_{2peak}$ and distance ambulated in the shuttle walk test, than with the 6-min walk test (Green et al., 2001). Detail regarding execution of submaximal walk, cycle and step tests and the use of HR and perceived exertion can be found in Chapter X (Field-based Assessments).

SUMMARY OF KNOWLEDGE AND FUTURE DIRECTIONS

When working with clinical populations it is always important to know where the boundaries of our roles and competencies lie with respect to the patient, the disease and the assessments employed. It is likely that our work in these scenarios will evolve alongside important developments in our understanding of CVD and their prevention, detection, and treatment. It is incumbent on the sport and exercise science practitioner to be familiar with an ever-changing literature base related to CVD. Specifically, we should endeavour to keep abreast of advancing literature related to new methods of assessment, as well as data pertaining to the accuracy and quality of any estimated or measured outcomes.

Biographies

Dr Victoria S Sprung, Research Institute for Sport & Exercise Science, Liverpool John Moores University. *Tori is an exercise physiologist with ~10 years' experience of conducting clinical trials (CTIMP & exercise/physical activity interventions) in people living with chronic disease.*

Professor John P. Buckley, Shrewsbury Centre for Active Living, University of Chester. *John is a Professor of Applied Exercise Science with >20 years' frontline experience working as a practitioner in CVD prevention and rehabilitation exercise. John has served on UK and International Panels for writing Standards and Polices in CVD prevention and rehabilitation, including the British Association for CV Prevention and Rehabilitation (President 2009-2011), The International Council of CV Prevention and Rehabilitation (Founding Chair 2011 - 2016), and the WHO Panel of Ischaemic Heart Disease and Rehabilitation (2017 – 2021).*

Dr David L. Oxborough, Research Institute for Sport & Exercise Science, Liverpool John Moores University. *David is a clinical cardiac physiologist specialising in echocardiography in clinical and athletic populations with >20 years' experience working in various healthcare settings.*

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