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Maximal Aerobic Testing in Spinal Cord Injury: Considerations from Clinical Experience

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Abstract

Increasing participation in physical activity is a primary clinical concern in those with spinal cord injury (SCI). The measurement of maximal aerobic capacity in those with spinal cord injury (SCI) is now being used to help predict habitual physical activity levels after SCI, as well as evaluate SCI athletes. As in able-bodied participants, precise execution of the maximal aerobic test is essential in order to obtain valid results. Many special considerations exist when performing a maximal aerobic testing in those with SCI. Most notably this includes using an arm-crank cycle, however further considerations exist such as: frequent evaluation of blood pressure and symptoms of syncope, unreliable heart rate response in those with SCI above the 5th thoracic spinal level, importance of bladder evacuation prior to testing, and the special attention required to decide work rate depending on lesion level and completeness. This review will detail these considerations from the perspective of clinical experience, as well as provide explain the underlying principles.

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Introduction

Engaging in routine physical activity is an effective primary and secondary preventive strategy against at least 25 chronic conditions (Warburton et al., 2006a). Aerobic fitness (an attained state) in particular is associated with the primary and secondary prevention of various chronic conditions, and premature all-cause and disease-specific mortality (Warburton et al., 2006a). In fact, aerobic fitness has a much stronger relationship with health status than physical activity levels (Warburton et al., 2010; Warburton, 2012; Williams, 2001). Aerobic fitness also has important implications for the maintenance of functional independence across the lifespan (Paterson and Warburton, 2010; Warburton et al., 2010).

Maximal aerobic power is defined as the maximum capacity to transport and utilize oxygen (Warburton et al., 2006a). The standard protocol for evaluating maximal aerobic power involves the measurement of expired gases during incrementally increasing intensity exercise, until volitional cessation or signs and symptoms of fatigue occur. From a traditional perspective, a plateau in oxygen consumption (with increasing exercise intensity) is considered to reflect maximal aerobic power, and is the standard criterion indicator of aerobic

exercise capacity/tolerance (Astrand, 1976). However, it is important to highlight that many patients and apparently healthy individuals may not achieve a plateau in oxygen consumption and therefore the term peak oxygen consumption is to describe this value, as the practitioner often cannot be certain that a true maximal value was attained.

Individuals with spinal cord injury (SCI) are at a markedly increase risk for the development of cardiovascular disease and have considerably lower maximal aerobic power values than the general able-bodied population (Myers et al., 2012; Myers et al., 2007; Warburton et al., 2007; Warburton et al., 2006b). Engaging in routine physical activity has been promoted widely to improve the health and well-being of persons living with SCI (Myers et al., 2012; Phillips et al., 2011; Warburton et al., 2007). In fact, habitual physical activity and/or engaging in planned aerobic exercise training has been shown to improve significantly several markers of cardiovascular health (Phillips et al., 2011; Phillips et al., 2010).

The loss of motor function and marked autonomic dysfunction make traditional maximum aerobic power testing difficult in those with SCI. Individuals with high lesion levels (i.e., T₅ injuries and above) typically have more severe physical and autonomic limitations to performing exercise; however, many of these can be mitigated with proper preparation and implementation of surrogate tools. The obvious limitation to both high (T₅ and above) and low level SCI (T₆ and below) is that participants cannot ambulate with their lower body necessitating the use of upper body exercise for the evaluation of maximal aerobic power. Over ground wheelchair propulsion, electrical stimulation exercise, and arm cranking can be used to

evaluate maximal aerobic exercise capacity in SCI (Jacobs and Nash, 2004). The most ubiquitous tool, however, and the device discussed in this paper, is the arm crank cycle. Several models of stationary arm-crank cycles exist; two common manufacturers are SCIFIT (Tulsa, Oklahoma) and Monark (Vansbro, Sweden).

We have performed numerous maximal aerobic power tests with persons living with SCI in clinical and high performance settings working as qualified exercise professionals (i.e., Certified Exercise Physiologists (AP, DW)) and a Registered Nurse (RF). This practical review is meant to disseminate our experience as practitioners directly employing this test, and explain our experience founded upon evidence-based best practice and sound physiological evidence.

General Considerations

It is recommended strongly that the qualified exercise professional and other allied healthcare professionals use the new physical activity participation and risk stratification strategy (i.e., the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and the electronic Physical Activity Medical Readiness Questionnaire (ePARmed-X+. www.eparmedx.com)) with all persons living with SCI that wish to undergo an exercise stress test (Warburton et al., 2011a; Warburton et al., 2011c; Warburton et al., 2011d; Warburton et al., 2011e). This risk stratification strategy will assist with the effective clearance of participants, and allow for further insight into the need for more advanced medical clearance. This includes the ability to monitor the presence of other known comorbidities.

Maximal Aerobic Power Testing in Spinal Cord Injury

Careful interview before testing will allow the practitioner to evaluate any unresolved injuries or bilateral limitations to exercise. High intensity exercise (including maximal or near maximal aerobic exercise) can result in musculoskeletal injury (particularly of the shoulder) in individuals that routinely ambulate using wheelchairs (Warburton et al., 2011b; Warburton et al., 2011c). Therefore, if signs or symptoms associated with musculoskeletal injury (such as shoulder pain) are observed the exercise testing should be delayed until appropriate time for healing has been given. Medical referral to an appropriate healthcare professional licensed to deal with this form of injury may be warranted.

The height of the arm crank relative to the participant can influence greatly the results of the test. For this reason, we recommend strongly standardizing the arm crank height by matching the height of the axis of the arm crank to the shoulder of the participant (Jacobs and Nash, 2004). Also, the arm should still be slightly flexed at the point the arm is furthest away from the body. In our practice, we generally have not encountered thermoregulatory disturbance-related issues, which can occur due to the loss of sudomotor responses below the SCI level. However, careful attention should be paid to ensure that the participant is well hydrated before initiating the test (Jacobs and Nash, 2004).

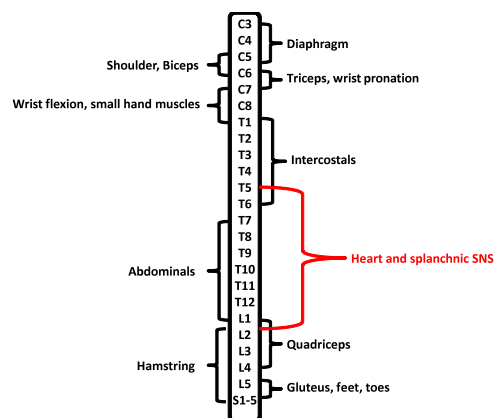
High Level Lesions

Health and Safety

The health and safety of the participant is paramount regardless of the disease or condition. Typically, physician approval would be obtained before testing an individual with high-level SCI.

Ensure that the bladder has been emptied prior to initiating exercise as a full bladder may cause dangerous increases in blood pressure. It is typically unsafe to test those with lesion levels above C₄ (sometimes C₅) and above as they will be have impaired control over the diaphragm and may be dependent on a respirator (Figure 1) (Krassioukov and Claydon, 2006). Of particular pertinence to those with high level SCI, specific consideration should be taken regarding their current blood pressure. In this injury type, resting blood pressure will be significantly reduced due to reductions in resting vasomotor tone (Krassioukov, 2009). In a hospital setting with clinical staff readily available, it is generally acceptable to proceed with the test if systolic blood pressure is above 110 mmHg. If the participant has systolic blood pressure below 110 mmHg, a physician may order a 5-10 mg dose of Midodrine hydrochloride. Approximately, 45 minutes after administration, blood pressure is usually improved enough to proceed.

Figure 1: A diagram of relevant motor and autonomic pathways emerging from the spinal cord. Black lines indicate motor neurons emerging from the spinal cord while red lines indicate post-ganglionic sympathetic neurons.



It is essential to monitor blood pressure every 60-120 seconds during incremental to maximal aerobic testing in SCI. If blood pressure decreases significantly and/or the participant reports dizziness/ nausea/ confusion, the test should be terminated and the subject reclined in his/her chair until cessation of pre-syncope symptoms. Alternatively, if blood pressure increases significantly with a concomitant sweating and decrease in heart rate, the test should be terminated as this suggests a bout of autonomic dysreflexia (AD) (Krassioukov and Claydon, 2006). These spikes in blood pressure are dangerous and can be fatal. Ensure with clinical staff that the cause of AD has been corrected, the bladder is empty, and that the preceding catheterization has been properly administered. After blood pressure has stabilized for 5-10 minutes, re-initiating the test is usually approved by a physician.

Exercise Considerations

Those above C₆ will have severe limitations in the ability to rotate the arm crank due to loss of motor function in the shoulders, biceps, forearms, and hands (Figure 1). If some arm function exists without fine motor movement in the hands, specialized hand straps can be applied which directly attach the arm crank to the forearm. This allows a participant who is unable to grip the crank to perform the test. To initiate the test, at 60 revolutions per minute, the work rate selected should be 5 W increasing 5-10 W per minute.

Effects of Injury on Traditional Markers

Sympathetic outflow to the heart is typically disrupted in those with SCI above T₅ (Scott et al., 2011). As such, heart rate responses to exercise will be

abnormal. For this reason, heart rate should not be used as an indicator of intensity or effort in this population. Although not suitable for the evaluation of effort, a practitioner should still monitor heart rate as decreases may indicate bouts of autonomic dysreflexia, while increases in heart rate during exercise indicate some preservation of descending preganglionic sympathetic pathways across the site of injury (Krassioukov, 2009; Krassioukov and Claydon, 2006). In lieu of heart rate, rating of perceived exertion should be used to evaluate effort and intensity.

As seen in able-bodied individuals, if the maximal aerobic test is correctly administered, participants should present with a plateau in oxygen consumption with a concomitant increase in ventilation as work rate continues to increase above the maximal aerobic capacity. This value should be utilized as the indicator of true maximal aerobic capacity. The injury level and completeness also varies the muscle available to recruit in order to utilize oxygen and produce carbon dioxide. As such, no clear normative values exist for maximal aerobic capacity although typically the values range approximately from 5 ml O₂/min/kg to 20 ml O₂/min/kg depending on primarily the lesion level and completeness, but also training status (Burkett et al., 1990).

Low Level Lesions

Health and Safety

When performing a maximal aerobic test in those with low lesion levels below T₆, many of the same considerations exist as when testing those with higher, more severe SCI. As those with low lesion levels typically have sufficient sympathetic vasomotor tone, there need not be as close attention paid to blood pressure, autonomic dysreflexia, and/or symptoms

suggestive of syncope. Similar attention should be paid as when performing a maximal aerobic testing in able-bodied individuals.

Exercise Considerations

Resting heart rate will be higher in those with low level SCI as compared to able-bodied individuals (Krassioukov, 2009). In most cases, a greater initial work rate should be used, and the intensity can increase more rapidly when testing those with lower level injuries. Typically, at 60 revolutions per minute, an initial work rate of 10-15 W with 10 W increases per minute can be well tolerated. Special attention should be taken to ensure secure attachment of the arm crank to either a wall or the floor, and that both right and left brakes are applied to the wheel-chair. Significant force can be generated, especially in larger and more fit participants at the higher stages of resistance. Equipment coming loose and moving away from the participant can compromise the reliability and validity of the test.

Effects of Injury on Traditional Markers

In contrast to those with higher level SCI, heart rate may have an exaggerated response to exercise as compared to able-bodied individuals. This may compensate in part for a lower exercise stroke volume. However, heart rate can still be used effectively as an intra-participant estimate of effort and intensity in those with low level SCI. A measure of self-reported perceived exertion (such as the Borg scale) should be used as a supplement index of effort. Again if the maximal aerobic test is correctly administered, when the work-rate rises above the maximal aerobic power participants should present with a plateau in oxygen consumption with

increasing ventilation and carbon dioxide production. This value should be utilized as the indicator of true maximal aerobic capacity. It is important to highlight that our laboratory employs supramaximal exercise intensities to confirm the attainment of maximal aerobic power (Warburton and Bredin, 2012). However, many other laboratories (particularly in clinical settings) are content with the attainment of peak aerobic power criteria and forgo the need for a supramaximal confirmatory stage and/or the presence of a plateau in oxygen consumption (as required by a true maximal aerobic power test).

No clear normative values exist for maximal (or peak) aerobic power; however, typically the values range from 18 to 30 mL/kg/min (depending on training status, and level of injury and completeness) (Burkett et al., 1990).

Conclusions

Maximal aerobic power testing is an important tool in the evaluation of aerobic health and the risk for functional dependence in those with SCI. Many special considerations need to be taken to ensure a safe and valid test when working with those with SCI. Extra attention needs to be taken when dealing with those with high level lesions to ensure stable blood pressure and avoid syncope. Further, heart rate is limited predictor of exertion in those with high level SCI. In those with lower level lesions, similar care needs to be taken as when performing a maximal aerobic power test in able-bodied individuals; however care should be taken to stabilize both the chair and arm-crank.

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Authors' Qualifications

The author's qualifications are: Aaron Phillips, M.Sc., Ph.D. Candidate (Medicine), CEP, Renee Fougere, BScN, Darren Warburton, MSc, PhD, CEP.

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