Accepted Manuscript

Title: Exercise and Sports Science Australia (ESSA) Position Statement on Exercise and spinal cord injury

Author: Sean M Tweedy Emma M Beckman Tim Geraghty Daniel Theisen Claudio Perret Lisa A Harvey Yves C Vanlandewijck

PII: S1440-2440(16)00032-3
DOI: http://dx.doi.org/doi:10.1016/j.jsams.2016.02.001
Reference: JSAMS 1283

To appear in: Journal of Science and Medicine in Sport

Received date: 30-9-2015
Revised date: 14-1-2016
Accepted date: 5-2-2016

Please cite this article as: Tweedy SM, Beckman EM, Geraghty T, Theisen D, Perret C, Harvey LA, Vanlandewijck YC, Exercise and Sports Science Australia (ESSA) Position Statement on Exercise and spinal cord injury., Journal of Science and Medicine in Sport (2016), http://dx.doi.org/10.1016/j.jsams.2016.02.001

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.
Title: Exercise and Sports Science Australia (ESSA) Position Statement on Exercise and spinal cord injury.

Authors: Sean M Tweedy, Emma M Beckman, Tim Geraghty, Daniel Theisen, Claudio Perret, Lisa A Harvey, Yves C Vanlandewijck

a The University of Queensland, School of Human Movement Studies, Australia
b Queensland Spinal Cord Injuries Service, Princess Alexandra Hospital, Metro South Health, Brisbane, Australia
c Sports Medicine Research Laboratory, Public Research Centre for Health, Luxembourg, Grand-Duchy of Luxembourg
d Institute of Sports Medicine, Swiss Paraplegic Centre Nottwil, Switzerland
e John Walsh Centre for Rehabilitation Research, Sydney Medical School/Northern, University of Sydney, Australia
f Katholieke Universiteit Leuven, Faculty of Kinesiology and Rehabilitation Sciences, Belgium

Corresponding Author:

Sean Tweedy, PhD

School of Human Movement and Nutrition Sciences (#26B), Rm 526

The University of Queensland | St Lucia Campus

Abstract

Traumatic spinal cord injury (SCI) may result in tetraplegia (motor, sensory and/or autonomic nervous system impairment of the arms, trunk and legs) or paraplegia (impairment of the trunk and/or legs only). The adverse effects of SCI on health, fitness and functioning are frequently compounded by profoundly sedentary behaviour. People with paraplegia (PP) and tetraplegia (TP) have reduced exercise capacity due to paralysis/paresis and reduced exercising stroke volume. TP often further reduces exercise capacity due to lower maximum heart-rate and respiratory function. There is strong, consistent evidence that exercise can improve cardiorespiratory fitness and muscular strength in people with SCI. There is emerging evidence for a range of other exercise benefits, including reduced risk of cardio-metabolic disease, depression and shoulder pain, as well as improved respiratory function, quality-of-life and functional independence. Exercise recommendations for people with SCI are: ≥30min of moderate aerobic exercise on ≥5d/week or ≥20min of vigorous aerobic ≥3d/week; strength training on ≥2d/week, including scapula stabilizers and posterior shoulder girdle; and ≥2d/week flexibility training, including shoulder internal rotators. These recommendations may be aspirational for profoundly inactive clients and stratification into “beginning”, “intermediate” and “advanced” will assist application of the recommendations in clinical practice. Flexibility exercise is recommended to preserve upper limb function but may not prevent contracture. For people with TP, Rating of Perceived Exertion may provide a more valid indication of exercise intensity than heart rate. The safety and effectiveness of exercise interventions can be enhanced by initial screening for autonomic dysreflexia, orthostatic hypotension, exercise-induced hypotension, thermoregulatory dysfunction, pressure sores, spasticity and pain.
1. Background

Spinal cord injury (SCI) refers to damage to neural elements of the spinal canal (spinal cord, cauda equina and spinal nerves), frequently resulting in permanent impairments of motor, sensory and/or autonomic function\(^1,2\). Aetiology may be traumatic (e.g., motor vehicle accident and falls) or non-traumatic (e.g., myelomeningocele, spinal stenosis, transverse myelitis and tumor)\(^2\).

Spinal cord injury profoundly affects functioning at the level of body systems (e.g., neuromusculoskeletal and cardiovascular functioning), person (e.g., walking, grasping, lifting and carrying) and society (e.g., employment, sports participation, social engagement)\(^3\). It is extremely costly in human, social and economic terms\(^3\). The global incident rate of SCI is estimated at 23 cases per million (179,312 cases per annum), although there is considerable regional variation, from North America (40 per million) to Australia (15 per million)\(^3\). Globally, the incidence of SCI is highest among males aged 18-32 years and, in developed countries with ageing populations, people over 65 years\(^3\). Worldwide, more than 2 million people live with an SCI\(^3\). Given the high cost, geographic spread and relatively high incidence of SCI, evidence-based methods which improve outcomes for people with SCI are critical.

Physical activity is defined as “any bodily movement produced by skeletal muscle that results in caloric expenditure”\(^4\). Exercise is a specific type of physical activity that is planned, structured and repetitive and done to improve or maintain fitness\(^4\). Evidence indicates that people with SCI are profoundly inactive\(^5\) and this inactivity is causally linked to an increased risk of preventable diseases that compound the primary effects of SCI\(^6,7\). Exercise interventions are an effective means of increasing physical activity and reducing preventable disease risk in people with SCI\(^7\). Additionally, specific types of exercise have been
shown to enhance health, fitness and functioning in people with SCI. The aim of this Position Statement is to provide practitioners with evidence-based recommendations for prescription of safe, effective exercise interventions for adults with chronic SCI (≥ six months post-injury). Between 70%\(^5\) and 84%\(^9\) of people with SCI use a hand-rim propelled wheelchair, and therefore they are the primary focus of this statement, although much of the information provided is relevant to people with SCI who have more severe activity limitations (e.g., people who use power wheelchairs) as well as less severe (e.g., people with SCI who walk). The Statement focuses on exercise using voluntarily activated muscles rather than assistive technology such as, Functional Electrical Stimulation and Body Weight Supported Treadmill Training. Practitioners interested in these two modalities are directed to recent reviews cited in the reference list\(^{10,11}\).

2. Motor, sensory and autonomic effects of SCI

The extent of motor, sensory and autonomic dysfunction resulting from SCI depend upon the segmental level of the injury and the completeness of the injury\(^12\). Tetraplegia (preferred to quadriplegia) refers to injury to any of the spinal segments from C1 to C8 and results in impairments of arm, trunk and leg function\(^1\). Paraplegia (PP) refers to injury in the thoracic, lumbar or sacral segments, while arm function is spared. Approximately 53% of SCI results in tetraplegia (TP) and 47% in PP\(^12\).

Motor and sensory completeness of an SCI is classified according to the American Spinal Injury Association (ASIA) Impairment Scale (AIS)\(^1\). There are five AIS classifications, from AIS A (complete, no motor or sensory function in sacral segments S4-S5) to AIS E (a person with initial deficits who has normal motor and sensory function at the time of assessment)\(^1\). The AIS scale does not include assessment of autonomic completeness, which must be assessed
separately\textsuperscript{13}. As acute management of SCI improves, the proportion of incomplete SCI is increasing\textsuperscript{14}. Approximately 65% of SCI are incomplete, with incomplete TP (38\%) being more common than incomplete PP (27\%)\textsuperscript{12}.

Table 1 presents the motor, sensory and autonomic function typical of a person with an AIS A injury (i.e., motor and sensory complete) that is also autonomically complete. The third column presents the typical profile of a person whose lowest intact segmental level is C1, C2 or C3, and each subsequent column presents the profile of a progressively lower segment or group of segments. Table 1 illustrates that complete injuries can result in an extremely wide range of functional profiles - from ventilator-dependent power wheelchair users with significant cardiorespiratory compromise, to independent walkers with no cardiovascular impairments. Table 1 also indicates that when injuries are motor, sensory and autonomically complete, functioning is generally predictable, increasing with lower segmental level of injury. However, when injuries are incomplete (i.e., AIS classification B, C or D), functioning cannot be predicted, even when segmental level is identical – a sample of people with a C4 SCI that is classified AIS C may include people who require a power wheelchair for mobility through to people who are able to walk independently. In addition to the effects of lesion level and lesion completeness, the functioning of a person with SCI is also affected by age, physical activity level and comorbidities such as spasticity, contractures and pain.

3. Exercise capacity in SCI

Many people with SCI are unable to engage in lower-limb exercise and must use upper-limb modes such as wheelchair pushing or upper-limb ergometers (e.g., arm-crank or wheelchair). This constraint is important because, compared to lower limb exercise, upper limb exercise elicits a considerably reduced cardiovascular response\textsuperscript{15}. For example, when people without SCI perform arm cycling, maximal power output (PO\textsubscript{max}) and VO\textsubscript{2peak} are reduced by
approximately 40% and 25% respectively compared with leg cycling\textsuperscript{15}. Efficiency is also reduced - \( \text{O}_2 \) uptake (and therefore physical strain) for any given power output is greater for arm cycling than for leg cranking.

When exercise capacity is assessed using arm-crank ergometry, there is no significant difference between \( \text{VO}_{2\text{peak}} \) for people with or without paraplegia (PP) \textsuperscript{15}. Parity is achieved at least partly because habitual wheelchair use leads to physiological adaptations in the upper-limb musculature of PP, reducing glycogenolysis and increasing the rate of lipid utilisation\textsuperscript{15}. Even with the limitations inherent to upper-limb exercise, SCI athletes can achieve a high \( \text{VO}_{2\text{peak}} \) (e.g., a mean of 40ml.kg\textsuperscript{-1}.min\textsuperscript{-1} for a Paralympic wheelchair basketball team\textsuperscript{16}).

The above evidence notwithstanding, SCI adversely affects exercise capacity for a number of reasons. Firstly, as lesion level increases, voluntarily activated muscle mass decreases (see Table 1), reducing oxidative capacity and therefore maximal oxygen uptake and maximum caloric expenditure from exercise. This effect is particularly pronounced in TP because the muscles required for arm exercise are partially paralysed in addition to paralysis of the trunk and legs\textsuperscript{15}. Secondly, as lesion level increases, sympathetic vasoconstrictive capacity gradually diminishes, reducing venous return and, in accordance with the Frank-Starling mechanism, exercising stroke volume does not rise to the same extent as non-disabled. At submaximal exercise levels, cardiac output can be maintained by a compensatory increase in heart rate, but this is not possible during maximal exercise, reducing maximal exercise capacity.

For TP, two additional factors negatively impact on exercise capacity. The first is that, for those with absent or reduced cardiac sympathetic innervation, heart rate increases rely to a proportionally greater extent on parasympathetic withdrawal and circulating catecholamines\textsuperscript{15}, and maximal heart rate may be as low as 130bpm\textsuperscript{15}. However, it should be noted that recent evidence suggests that even those with AIS A tetraplegia may retain autonomic function that is
sufficient to improve cardiovascular responses to exercise\textsuperscript{13}. The second negative impact is that, while respiratory function is normal or near normal in most PP (see Table 1), it is approximately 60\% of normal values in TP\textsuperscript{15}. The combination of reduced active muscle mass, impaired venous return, neurologically limited maximum heart rate and decreased respiratory function significantly reduces exercise capacity in TP compared with PP. Exercise capacity norms have been previously published: for TP, VO\textsubscript{2peak} of \(<7.6 \text{ ml.kg}^{-1}.\text{min}^{-1}\) is poor and \(>16.95 \text{ ml.kg}^{-1}.\text{min}^{-1}\) is excellent\textsuperscript{17}; for PP, VO\textsubscript{2peak} of \(<16.5 \text{ ml.kg}^{-1}.\text{min}^{-1}\) is poor and \(>34.4 \text{ ml.kg}^{-1}.\text{min}^{-1}\) is excellent.

4. Benefits of Exercise

There are 2 exercise benefits for which there is very strong and consistent evidence – improved cardiorespiratory fitness (CRF) and improved muscular strength\textsuperscript{6}. Evidence indicates that CRF of both TP and PP improves in response to upper-limb aerobic training or circuit training\textsuperscript{16,18-20}. Resistance training also improves CRF in PP\textsuperscript{20}. In a review of 14 exercise training studies, VO\textsubscript{2peak} improved by a mean of \(17.6 \pm 11.2\%\) and PO by \(26.1 \pm 15.6\%\), with a trend for greater gains in PP than TP\textsuperscript{16}.

Clinically significant changes in the strength of non-paralysed muscle groups can be achieved through resistance training and circuit training\textsuperscript{16,18,19,21}. However evidence for enhancing the strength of partially paralysed muscles (e.g., resulting from incomplete SCI or muscle groups with partial segmental innervation) through voluntary activation is mixed (see Section 7 – Gaps in the Literature).

The remainder of this Section presents exercise benefits for which there is “emerging evidence”, meaning evidence has been published in peer reviewed literature and is either supported by a plausible mechanism of action, or is consistent with findings from exercise training studies in the general population,
but which may not have used optimal research design or has not been replicated. One reason that stronger evidence is not available is that the SCI population is inherently heterogeneous (due to variations in lesion level, lesion completeness and comorbidities) and prevalence in society is relatively low. These factors act as a barrier to recruitment of the large, homogeneous samples required for rigorous scientific research and generation of high-quality evidence regarding the benefits of exercise for people with SCI.

Cross-sectional evidence indicates that the cardiometabolic risk profile of people with SCI who regularly perform aerobic exercise is significantly better than in those who do not: BMI and percentage fat mass are lower, total daily energy expenditure is higher and both lipid profile and glucose homeostasis are better. Aerobic exercise interventions confer clinically important improvements in lipid lipoprotein and glucose homoeostasis. Exercise interventions can augment weight reduction induced by caloric restriction, but to date, exercise interventions alone have not been shown to improve body composition or reduce weight in people with SCI.

In people with TP, reduced respiratory function limits exercise capacity and increases the risk of pulmonary infection. Evidence indicates that specific training techniques for inspiratory and expiratory muscles can improve respiratory function and may improve peak exercise response. Sufficiently intense aerobic exercise training (>70% maximum heart rate) may improve elements of respiratory function.

Research indicates exercise may enhance functional independence and activities of daily living in people with SCI. Furthermore, higher CRF is strongly correlated with increased participation in activities of daily living such as cleaning and wheeling.
The rate of depression among people with SCI is four times that of the general population and health-related quality of life (HRQOL) is significantly lower. Exercise interventions can decrease depression and increase quality of life in people with SCI. Moreover, people with SCI who are exercise regularly are likely to have greater life satisfaction than those who do not.

SCI is associated with sublesional osteopenia and osteoporosis, leading to increased fracture risk. Cross-sectional studies have demonstrated that physically active TP and PP have significantly better sublesional and general bone health than their inactive counterparts, suggesting that regular exercise may maintain bone health.

Neuropathic pain affects 65-85% of people with SCI and may result from peripheral, spinal or cerebral mechanisms. Additionally, upper-limb pain of musculoskeletal origin affects 50-70% of people with SCI, and it is hypothesised that it is primarily due to constant use of the arms for transfers and wheelchair propulsion. However the hypothesis does not explain why non-athletes are twice as likely to develop shoulder pain as athletes. Higher muscular strength is associated with less upper-limb pain in both TP and PP, and appropriate strength and flexibility training (e.g., strengthening scapula stabilisers and rotator cuff) has been shown to reduce shoulder pain in both groups. A randomised controlled trial of a combined aerobic and resistance training exercise program (60-90min per session, two sessions per week for nine months) found that, compared to a control group, the intervention group significantly reduced general pain scores and depression.
5. Exercise Guidelines

As indicated at the beginning of Section 4, to date, the relatively low prevalence of SCI and the inherent heterogeneity of the SCI population have adversely affected the quality and quantity of exercise training evidence in people with SCI. Consequently, if exercise guidelines were to be based solely on SCI-specific exercise training evidence, they would be correspondingly weak. Importantly however, the SCI-specific evidence presented in Section 4 is consistent with findings in the general population for which there is evidence of the very highest level. Specifically, exercise training positively influences CRF, cardiometabolic risk profile, strength, mental health, bone health and physical functioning. This consistency indicates that, in the absence of compelling evidence to the contrary, exercise guidelines for people with SCI should be consistent with those for the general population. Therefore, the aerobic, strength and flexibility exercise recommendations presented in Table 2 are generally consistent with those for the general population but, where available, incorporate SCI-specific evidence. This approach is consistent with the approach adopted by reputable, international health authorities\textsuperscript{45-47} for the development of exercise recommendations for people with disabilities, as well as one other recently published exercise guideline for people with SCI\textsuperscript{7}.

Aerobic exercise recommendations presented in Table 2 are more than 3 times the minimum volume of aerobic activity recommended for people with SCI in 2011 by Martin Ginis et al\textsuperscript{6}. These guidelines have recently been re-published\textsuperscript{48} and recommend a minimum volume of 20 min of moderate intensity activity, 2x/week (i.e., 40 min/week)\textsuperscript{6,48}. In the general population there is unequivocal evidence of a dose-response relationship between aerobic exercise volume (dose) and reduced risk of morbidity and mortality (response)\textsuperscript{49}. The relationship is curvilinear, such that reductions in morbidity and mortality that are conferred by a given increase in exercise volume are greatest for people completing very low volumes of exercise (e.g., <30 min per week)\textsuperscript{49}. The best available evidence indicates that this feature of the dose response relationship can be generalised to people with disabilities, including people with SCI\textsuperscript{45-47}. Consequently, the risk of morbidity and mortality – including all-cause mortality, hypertension, coronary heart disease, type 2 diabetes mellitus, stroke, breast...
and colon cancer and depression\textsuperscript{7,45-47,49} – is likely to be significantly higher in people with SCI who complete only 40min/week of moderate intensity aerobic activity (recommended in the Martin Ginis guidelines), compared to those who habitually complete 150min/week, as recommended in this Position Statement.

One possible reason for the discrepancy between recommendations is that this Position Statement is aimed at professional practitioners with the capacity to stratify clients into “Beginning Clients”, “Intermediate Clients” and “Advanced Clients” (guidelines for stratification are described later in this section) and then apply the evidence-based recommendations appropriately in the clinical context. In contrast, the Martin Ginis guidelines are aimed at the general population of people with an SCI, providing population-level recommendations which are “appropriate for all healthy adults with chronic spinal cord injury, traumatic or non-traumatic, including tetraplegia and paraplegia…”

These different aims notwithstanding, practitioners should be aware that the best available evidence indicates the following\textsuperscript{7,45-47}: compared with a sedentary lifestyle, people with SCI who habitually complete the volume of aerobic activity recommended by Martin Ginis\textsuperscript{6} will significantly lower health-related morbidity and mortality risk; and the volume of aerobic activity recommended in this Position Stand (Table 2) will confer a reduction in health-related morbidity and mortality that is significantly greater than the reduction conferred by the Martin Ginis recommendations\textsuperscript{6} and which is much closer to the level of risk considered acceptable for the general population.

Recommendations for strength exercise are consistent with those recently published by the World Health Organisation\textsuperscript{45} and one SCI-specific guideline\textsuperscript{7}. Our recommendations for flexibility exercises are based on two SCI-specific publications\textsuperscript{7,50}, together with evidence from the general population\textsuperscript{4}.
In order to apply the recommendations presented in Table 2, practitioners should stratify clients with SCI into 3 broad categories:

1. **Beginning Clients** are not currently completing the recommended exercise volume for good health and, based on a conventional and safe rate of exercise progression, will be unlikely to reach that exercise volume in the next three months. A high proportion of clients will fall into this group, many with TP and/or multiple comorbidities. Even modest increases in exercise volume (e.g., 5min of moderate intensity activity per day) can meaningfully reduce disease risk in Beginning Clients;

2. **Intermediate clients** are not currently completing the recommended exercise volume for good cardiometabolic health but, based on conventional and safe rates of exercise progression, will be likely to reach that exercise volume in the next three months. Although the exercise recommendations in Table 2 are somewhat arbitrary, strong scientific evidence substantiates that this volume of exercise will confer a broad spectrum of significant health benefits;

3. **Advanced clients** are currently meeting or exceeding the recommended exercise volume for good health. While the number of clients in this stratum is small, it is likely that practitioners will have contact with these clients because they are more likely to seek out expertise. Evidence from the general population indicates that when exercise volumes reach extremely high levels (e.g., Ironman competitors) additional increases in exercise volume can increase health risk including the risk of musculoskeletal injury. Given the high incidence of overuse-related upper-limb pain and dysfunction in people with SCI, practitioners working with clients in this stratum must be aware of clinical practice guidelines for preservation and optimisation of upper-limb function in people with SCI.
6. **Special Considerations**

Thorough pre-participation screening will identify relevant SCI-specific special considerations for exercise. Key considerations are presented below. While the range is substantial, it should be noted that a review of supervised exercise training studies found that, providing proper precautions were taken, adverse events during exercise training were not common and those that occurred were not serious\(^5\).  

*SCI Aetiology* may have significant exercise implications. Traumatic SCI (frequently associated with limb and brain trauma) and non-traumatic causes of SCI (e.g., spina bifida, vascular malformation or spinal stenosis)\(^5\) may affect exercise physiology and/or biomechanics. Practitioners should be aware that SCI may not be the only (or even the major) impairment affecting exercise.

*Time since injury* is associated with a significant decrease in physical functioning and increase in comorbidities\(^5\). Exercise can ameliorate these declines but exercise-associated risk is increased\(^5\). Practitioners should individually tailor exercise interventions and be conservative with exercise progression.

*Muscular paralysis* substantially reduces the range of exercises that are possible for people with SCI. Therefore, practitioners should work cooperatively with the client to identify the core movements or activities the client can and cannot do. Assessment outcomes should include observations regarding client safety, exercise proficiency and any assistance or adapted equipment that he/she may require. The website [https://www.physiotherapyexercises.com/](https://www.physiotherapyexercises.com/) is an excellent resource, providing more than 300 aerobic, strength and flexibility exercises adapted for people with SCI. A compendium of the energy cost of 63 wheelchair-based activities can assist practitioners to prescribe activities of appropriate intensity\(^5\).
Tenodesis grip is used by people with TP in the absence of voluntary grasp. This grip is initiated by active wrist extension which induces passive flexion of the fingers and thumb to produce a functional grip. The strength and effectiveness of this grip is principally determined by the passive length-tension characteristics of the extrinsic finger and thumb flexors. Practitioners should assess the strength of this grip and be aware that its effectiveness will be reduced if the finger and thumb flexors are regularly stretched.

Autonomic dysreflexia (AD): AD affects individuals with SCI at T6 or above and results from a noxious afferent stimulus below the level of the lesion (e.g., over-distended bladder). Symptoms may be mild or extreme (e.g., blood pressure (BP) of 300/220, pounding headache, blurred vision) and can lead to stroke, seizures and death. In Australia, people at risk of AD are usually well educated regarding symptoms and carry an “Autonomic Dysreflexia Medical Emergency Card” with information on treatment and emergency contact details. Emptying the bladder prior to exercise can minimise risk. Management involves identifying and removing the noxious stimulus (e.g., occluded catheter), loosening tight stockings/bindings and sitting upright in order to minimise intracranial BP. AD is an absolute contraindication for exercise training.

Orthostatic hypotension (OH) is a decrease of ≥20mmHg in systolic BP, or 10mmHg in diastolic BP upon sitting up from a supine position. It is caused by blood pooling in the abdominal viscera and legs during lying, compounded by lack of muscular contraction during the postural change. Exertional hypotension (EH) is a decrease of ≥10mmHg in systolic BP during exercise, and occurs due to a combination of vasodilation in exercising musculature and inadequate vasoconstriction in the splanchnic bed and non-exercising musculature. Both EH and OH result in similar symptoms – light-headedness, dizziness and syncope - and both are best treated with recumbency, leg elevation and fluid ingestion. Risk management includes slow, controlled positional
change, a graduated introduction exercise, and BP monitoring. Regular exercise may improve tolerance of OH\textsuperscript{59}. Symptomatic hypotension (e.g., dizziness, nausea, pallor) is an absolute contraindication for exercise training\textsuperscript{16}.

*Thermoregulatory function* may be impaired. In hot conditions, inability to sweat and dilate superficial vasculature impairs heat loss during exercise, particularly in TP\textsuperscript{60} and, consequently, exercising core temperatures tend to be higher\textsuperscript{16}. Normal precautions against overheating can be complemented by hand cooling\textsuperscript{61}, foot cooling\textsuperscript{62}, ice vests\textsuperscript{63} and spray bottles\textsuperscript{64}. In cold conditions, impaired superficial vasoconstriction, shiver response and piloerection accelerate heat loss, increasing the risk of exposure\textsuperscript{60}.

*Sensory impairment* increases the risk of pressure sores and falls (through decreased proprioception) and can delay detection/diagnosis of serious injury (e.g., bony fractures) following collisions or falls. Sensation-related risk is increased with new activities, particularly those done out of the regular chair (e.g., on new exercise equipment or a new sports wheelchair); contact sports; and when atrophy is severe. Risk management strategies include clear identification of insensate areas via client self-report; clients using their own cushions where possible/practical; thorough skin checks for red areas following new activities; regular pressure relief during exercise (every 15-30min)\textsuperscript{55}; and appropriate protective sports equipment\textsuperscript{55}. Some evidence indicates that a healthy lifestyle, including exercise, is protective against recurrent pressure sores\textsuperscript{65}.

*Spasticity* is defined as a velocity dependent increase in muscle tone and hyperexcitability of the stretch reflex\textsuperscript{66} which can result in involuntary activation of paralysed muscles that is intermittent (spasm) or sustained. Approximately 80% of people with SCI are affected. Spasticity is associated with pain and contracture\textsuperscript{66}. Slow controlled positional changes may reduce the likelihood of eliciting muscle spasms, and stable positioning (including strapping) can
reduce the likelihood of an adverse event should spasm occur. While some limited evidence suggests stretch may provide short-term, temporary relief from spasticity, there is no high-quality evidence to suggest that these benefits are long lasting\textsuperscript{67}.

Table 3 presents medications commonly used in the management of SCI. These medications are usually taken on a stable long-term basis, and so people have often adapted to side effects. Some medications used by people with SCI can potentially enhance exercise performance (e.g., Midodrine) and are therefore on the World Anti-Doping Authority (WADA) banned list. People using such medications for therapeutic reasons may take part in competitive sport to the highest levels provided they apply for Therapeutic Use Exemption (TUE).

7. **Gaps in the literature**

As indicated, the exercise guidelines presented in Section 5 are based on the dose-response relationship between physical activity and disease-risk in the general population. This approach is necessary because previously mentioned research design problems frequently weaken evidence produced by SCI-specific exercise training studies, but also because exercise dose is frequently poorly documented\textsuperscript{22}. Multi-centre trials which permit recruitment of sufficiently large, homogeneous samples of people with SCI are required to address this problem\textsuperscript{22}.

Current best practice for increasing strength in partially paralysed muscles adapts established strength training principles, typically commencing with unresisted, gravity eliminated movements, progressing to gravity opposed movements and finally to gravity opposed movements with resistance\textsuperscript{55}. Recent evidence has demonstrated that circuit training elicited strength gains in people with TP\textsuperscript{19}. However emerging evidence indicates that non-paralysed and
partially paralysed muscles may respond differently to resistance training. For example, one study found that progressive resistance training of partially paralysed wrist extensor muscles did not enhance wrist strength\(^68\). Another study demonstrated that an isometric protocol which induced fatigue-related decreases in peak volitional torque in non-paralysed muscle, increased peak volitional torque in partially paralysed muscle\(^69\). Evidence is not strong enough to discontinue current best practice, but practitioners should be aware of its possible limitations, inform their clients and stay abreast of research developments.

Contractures are a common complication of SCI characterised by marked limitations in passive ROM of affected joints\(^70\). Contracture has a significant impact on activities of daily living and positioning for exercise, and is associated with pressure sores, sleep disturbances and pain\(^70\). Stretch and passive movements are widely used for the treatment and prevention of contractures, however, evidence demonstrating the effectiveness of these interventions is lacking, especially when only administered for short periods of time\(^70\). Given the severe consequences of contractures, the flexibility guidelines described in Section 5 (Exercise Guidelines) should be followed. However, practitioners should be aware of its possible limitations, inform their clients and stay abreast of research developments.

8. **Summary**

SCI and its co-morbidities adversely affect health, fitness and functioning, effects that are frequently compounded by profoundly sedentary behaviour. Exercise interventions have been shown to enhance health, fitness and functioning. Exercise capacity is reduced in all people with SCI, but particularly in people with TP. Strong, consistent evidence demonstrates that exercise improves CRF and muscular strength and there is emerging evidence for a range of other benefits (e.g., reduced risk of cardio-metabolic disease, depression and shoulder pain, and improved functional independence). People with SCI should complete \(\geq30\text{min of moderate aerobic exercise on }\geq5\text{d/week or }\geq20\text{min of vigorous aerobic }\geq3\text{d/week; strength training on }\geq2\text{d/week, including scapula} \)
stabilizers and posterior shoulder girdle; and ≥2d/week flexibility training, including shoulder internal rotators. These recommendations may be aspirational for profoundly inactive clients and stratification of clients into “beginning”, “intermediate” and “advanced” will assist practitioners to apply the recommendations appropriately in clinical practice and tailor programs accordingly. Flexibility exercise is recommended to preserve upper limb function but may not prevent contracture. The safety and effectiveness of exercise interventions can be enhanced by initial screening for AD, OH, EH, thermoregulatory dysfunction, pressure ulcers, spasticity and pain.
References


Table 1: The motor, sensory and autonomic function typical of a person with an AIS A spinal cord injury that is also autonomically complete, from C1 – S4. SCI segmental levels are indicated in the header row and indicate the lowest intact segment/s. The motor profile represents that typically attained by people who are young and otherwise healthy.

<table>
<thead>
<tr>
<th>Voluntary Motor Function</th>
<th>C1-3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7-C8</th>
<th>T1-T5</th>
<th>T6-T12</th>
<th>L2-L3</th>
<th>L4-L5</th>
<th>S2-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional grasp</td>
<td>None</td>
<td>Reduced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>Mobility</td>
<td>Power Wheelchair (mouth, chin or voice controlled)</td>
<td>Power wheelchair (arm/hand controlled) or hand-rim propelled Wheelchair</td>
<td>Hand-rim propelled Wheelchair</td>
<td>Hand-rim propelled Wheelchair or walking* (limited)</td>
<td>Walking* or hand-rim propelled wheelchair (long distance)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfers: Chair-bench or floor-chair</td>
<td>Fully dependent for both</td>
<td>Some assistance chair-bench; dependent floor-chair</td>
<td>Some assistance chair-bench and floor-chair</td>
<td>Independent for both</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying to sitting</td>
<td>Dependent</td>
<td>Moderate assistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Independent</td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>Dependent for quiet sitting</td>
<td>Moderate assistance</td>
<td>Independent for quiet sitting but trunk support required for exercising</td>
<td>Independent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driving</td>
<td>No</td>
<td>Unassisted breathing (diaphragm)</td>
<td>Unassisted (diaphragm + some intercostal)</td>
<td>Normal or near normal</td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory function</td>
<td>Ventilator dependent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensory function</td>
<td>Includes light touch, pain, proprioception &amp; temperature</td>
<td>Present in head and neck</td>
<td>Present in head, neck and parts of arms</td>
<td>Present in head, arms and parts of the trunk</td>
<td>Present in head, arms, trunk and parts of the legs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomic function</td>
<td>Sudomotor and piloerector function</td>
<td>Sympathetic vasomotor function</td>
<td>Sympathetic cardiac innervation</td>
<td>Blood pressure responses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal above the level of the injury and absent below the level of the injury</td>
<td>Reduced in the arms and absent in splanchnic bed and legs</td>
<td>Normal in arms, absent splanchnic bed and legs</td>
<td>Impaired - susceptible to orthostatic hypotension (OH), exercise-induced hypotension (EH) and/or autonomic dysreflexia (AD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal in arms, reduced in splanchnic bed and absent in legs</td>
<td>Normal in arms and splanchnic bed, reduced in legs</td>
<td>Possible OH, EH or AD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal in arms and splanchnic bed, reduced in legs</td>
<td>Normal in arms and splanchnic bed, reduced in legs</td>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Requires lower-limb orthoses;
Table 2: Exercise Guidelines for People with SCI. These volumes of aerobic, strength and flexibility exercise are required in order for people with SCI to achieve good cardiometabolic health, physical fitness and functioning.

<table>
<thead>
<tr>
<th>Exercise component</th>
<th>Volume of exercise</th>
<th>Type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic exercise</strong></td>
<td>≥30min of moderate exercise on ≥5d/week; or ≥20min of vigorous exercise on ≥3d/week; or a combination of moderate and vigorous exercise on ≥3-5d/week. Can be accumulated in bouts of ≥10 min.</td>
<td>Exercise modes involving rhythmic contraction and relaxation of the largest available muscle groups. (e.g., wheelchair pushing, hand cycling, swimming)</td>
<td>Moderate intensity is:&lt;br&gt; - 3-6 METs; or&lt;br&gt; - 12-13 on BRPE scale; or&lt;br&gt; - 40-59% HRR. Vigorous intensity is:&lt;br&gt; - 6-8.8 METs&lt;br&gt; - 14-15 on BRPE scale&lt;br&gt; - 60-89% HRR.</td>
</tr>
<tr>
<td><strong>Muscular strength</strong></td>
<td>≥2d/week; Exercises covering the major muscle groups and should incorporate, if possible, 4-5 upper-limb exercises; 3 sets of each exercise (1 set = 8-12 repetitions) with 2-3 min recovery between each set; Moderate intensity (60%-70% 1RM or 12-13 on BRPE)</td>
<td>Free weights, pin loaded weights, body weight elastic bands or tubing, hydraulic resistance.</td>
<td>- Innervation of scapula stabilisers and posterior shoulder girdle is normal in people with PP and progressively decreases with higher lesion level in TP.</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>≥2d/week; Address the major muscle groups, including those of the neck, upper limbs, trunk and lower limbs; hold each static stretch for 10-30 seconds and complete 60 seconds of total stretching time for each flexibility exercise (e.g.,2x30sec or 4x15sec); static stretching (active or passive) should be done to a point in the range where there is a feeling of tightness, slight discomfort or, when sensation is impaired, to a point in the range at which resistance begins to increase; focus areas: stretching internal shoulder rotators, chest, and anterior shoulders.</td>
<td>Static stretching (described in this guideline) but also dynamic stretching.</td>
<td>- To limit impingement, avoid internal shoulder rotation when completing an overhead range of motion;&lt;br&gt; - Stretching of paralysed lower limbs in long-term wheelchair users should be conducted particularly cautiously due to increased incidence of sub-lesional osteopenia / osteoporosis.</td>
</tr>
</tbody>
</table>
Acronyms: MET – Metabolic equivalent; BRPE - Borg Rating of Perceived Exertion; HRR - Heart Rate Reserve

*For reasons presented in Section 3, untrained people with TP are only likely to achieve 2-3 METs;

†People with autonomically complete SCI above T6 have reduced cardiac sympathetic drive, and above T1 no sympathetic drive (see Table 1). In these clients, heart-rate based methods will not provide a valid indication of exercise intensity, but RPE can be used as a valid alternative."
<table>
<thead>
<tr>
<th>Therapeutic Purpose</th>
<th>Medication name (Generic)</th>
<th>Side-Effects Which May Affect Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce spasticity</td>
<td>Baclofen</td>
<td>Nausea; CNS depression; confusion; muscle weakness or pain; hypotension.</td>
</tr>
<tr>
<td>Dantrolene sodium</td>
<td></td>
<td>Drowsiness; dizziness; muscle weakness; fatigue</td>
</tr>
<tr>
<td>Botox (Botulinum toxin)</td>
<td></td>
<td>Muscle weakness; oropharyngeal problems; respiratory problems; pain; gait problems and falls.</td>
</tr>
<tr>
<td>Reduce neuropathic pain</td>
<td>Gabapentin</td>
<td>Weight gain; confusion; dizziness; somnolence; ataxia; fatigue.</td>
</tr>
<tr>
<td></td>
<td>Pregebalin</td>
<td>CNS effects include dizziness, somnolence, and insomnia; blurred vision; fatigue; weight gain.</td>
</tr>
<tr>
<td>Reduce bladder hypereflexia / spasm</td>
<td>Oxybutynin</td>
<td>Dry mouth, nausea; dizziness; drowsiness; blurred vision; asthenia (uncommon).</td>
</tr>
<tr>
<td>Relax bladder sphincter; improve bladder emptying</td>
<td>Prazosin</td>
<td>Orthostatic hypotension; syncope; drowsiness; dizziness; lack of energy; weakness.</td>
</tr>
<tr>
<td>Treat Urinary Tract Infection</td>
<td>Norfloxacin (antibiotic)</td>
<td>Nausea; headache; dizziness (all relatively uncommon).</td>
</tr>
<tr>
<td></td>
<td>Sulfamethoxazole -</td>
<td>Nausea, vomiting</td>
</tr>
<tr>
<td></td>
<td>Trimethoprim (antibiotic)</td>
<td></td>
</tr>
<tr>
<td>Treat low blood pressure/hypotension</td>
<td>Midodrine</td>
<td>Increased blood pressure; blurred vision; headache.</td>
</tr>
<tr>
<td>Prevent / treat blood clots</td>
<td>Warfarin sodium and other anticoagulants</td>
<td>Easy bruising / increased bleeding with injury</td>
</tr>
<tr>
<td>Treat impotence / erectile dysfunction</td>
<td>Sildenafil, Tadalafil,</td>
<td>Headache; dyspepsia; dizziness; back pain; nasal congestion; flushing.</td>
</tr>
<tr>
<td></td>
<td>Vardenafil</td>
<td></td>
</tr>
</tbody>
</table>