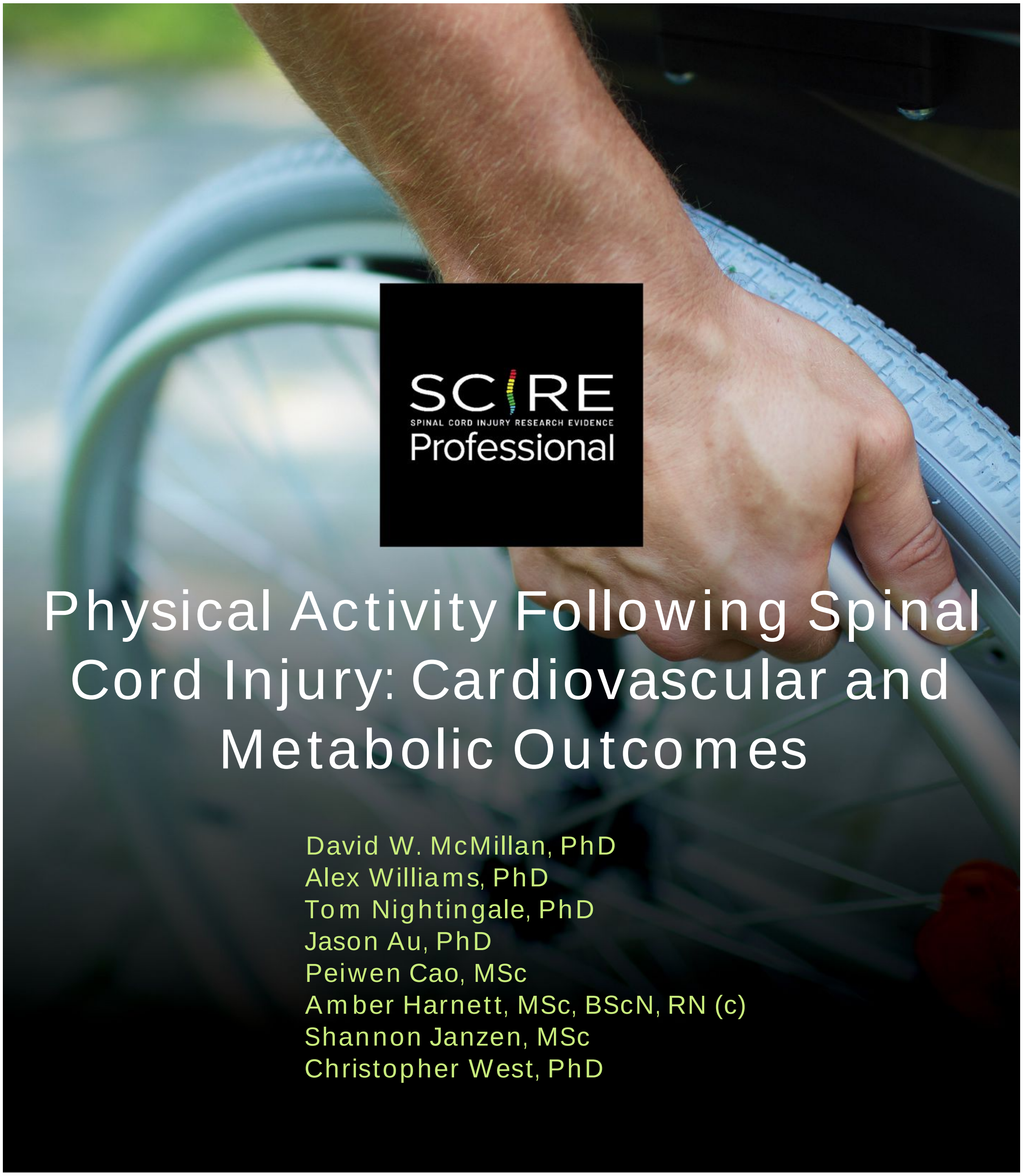

Physical Activity Following Spinal Cord Injury: Cardiovascular and Metabolic Outcomes

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Key Points

Effect of exercise on cardiorespiratory fitness

- Exercise training is a powerful tool to improve cardiorespiratory fitness in people with spinal cord injury.
- There is level 1 evidence that arm crank exercise, hybrid functional electrical stimulation leg exercise combined with arm exercise, and FES rowing improve cardiorespiratory fitness. The strongest evidence suggests that exercise should be performed 3 sessions per week for 8-12 weeks.
- There is mixed evidence mostly from fewer and less well controlled studies that functional electrical stimulation leg cycling, passive leg cycling, body weight supported treadmill training and wheelchair propulsion exercise can also improve cardiorespiratory fitness.

Effect of exercise on orthostatic hypotension

- Most of the evidence that exercise is beneficial to reduce the severity of orthostatic intolerance in individuals with SCI is from acute exercise trails that engage the lower limbs.
- There is 1 level 5 study that demonstrates chronic exposure to upper-body exercise training improves orthostatic tolerance.
- There is 1 level 4 study demonstrating chronic exposure to BWSTT does not improve orthostatic tolerance.

Effect of exercise on cardiometabolic risk

- The majority of studies that have investigated the effect of exercise on cardiometabolic risk have focused on blood lipids and markers of glucose tolerance/insulin resistance.
- There is level 1 evidence that arm-crank exercise improves insulin resistance but the effect on blood lipids is less clear.
- There is level 4 evidence that FES cycling, FES rowing and body weight supported treadmill training improves glucose tolerance.
- There is level 1 evidence albeit from very few studies to suggest that behavioural change interventions improve lipids and glucose tolerance.
- There is also preliminary Level 1A evidence that arm-crank exercise is also beneficial in reducing inflammation and improving anti-oxidant status.

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1 Executive Summary

Volitional movement is a defining feature of animals, and accordingly our body's physiological processes are intimately tied to physical activity. The deep biological connection of physical activity with human physiology means that our health is highly dependent on appropriate quality and quantity of activity. Despite the often profound impact that spinal cord injury (SCI) has on the ability to perform volitional movements, people with SCI of nearly all levels can participate in many forms of physical activity and in doing so have the opportunity to benefit their fitness, performance, and health. The types of activity that can be performed are based on individual abilities, and it is common for technology to be used to facilitate participation. The technology might facilitate activity, such as a manual wheelchair allowing for upper extremity muscles to drive overground propulsion. It is also possible for technology to generate the activity, such as robots that move the body or electrical activity that generates muscle contraction independent of the person's brain signals. Due to paralysis below the level of injury, people with SCI might have a very low absolute capacity to increase energy expenditure. Furthermore, altered control over the sympathetic arm of the autonomic nervous system can blunt the cardiovascular and endocrine response to activity. Nevertheless, as this chapter demonstrates, people with SCI can still benefit greatly from various forms of physical activity, and training-induced improvements do generally come with concomitant improvements in relative performance. Furthermore, the health-related benefits that stem from physical activity in people without SCI are also often reported in people with SCI.

This chapter focuses primarily on the effect of physical activity, including but not limited to exercise, as well as interventions on cardiovascular and metabolic outcomes that have health implications. We have purposely not included studies that have investigated the response to a single bout of exercise as the acute physiological response to exercise can differ greatly from the long-term benefits.

2 Introduction

SCI is one of the most debilitating chronic conditions that can affect people. When a SCI occurs at the cervical or high-thoracic spinal cord level it can immediately transition an active independent person to a dependent person with a significant burden of disability. Whilst the prevalence of SCI is relatively small (e.g., approx. 85,000 in Canada), the health care expenditures for individuals with chronic SCI are among the most expensive of any medical condition, largely due morbidity and premature mortality related to chronic secondary complications (Kreuger 2011; Krueger 2010). Cardiovascular disease is the leading cause of morbidity and mortality in individuals with chronic SCI (Garshick et al. 2005; Michael et al. 1999). In recent decades, there is a growing understanding that SCI also impacts metabolic function and population level data suggest that SCI increases the odds for metabolic disease, such as Type 2 diabetes, by severalfold. Targeting the chronic cardiometabolic complications of SCI would dramatically improve the health and well-being of people with SCI, and positively impact health care costs. Importantly, targeting cardiometabolic complications post-SCI are ranked among the highest priorities among persons with SCI (Anderson 2004).

The changes that occur in the cardiovascular system stem from multiple factors, but the effects of level/completeness of injury and physical deconditioning are arguably the most important. With respect to level of injury, when SCI occurs at or above the first thoracic level (T1) it immediately disrupts the sympathetic spinal pathways exiting the brainstem, which contains the cardiovascular control center that conveys signals to the heart and blood vessels. This loss of “normal neural control over the cardiovascular system” impairs the cardiovascular response to exercise (Gee et al. 2021; Teasell et al. 2000), causes orthostatic hypotension (OH) (Claydon & Krassioukov 2006), autonomic dysreflexia, impairs macro- and micro-vessel function, and predisposes people with SCI to acute cardiac events (Collins et al. 2006; Wan & Krassioukov, 2014). Conversely, when injury occurs at or below the T12 level then neural control of the cardiovascular system is essentially normal. With respect to injuries between the T1-T12 levels there can be a range of impairments to the cardiovascular system depending on the specific level and severity of injury. For a more comprehensive overview of the neuroanatomic implications that various levels/severities of SCI have for cardiovascular function several excellent reviews exist on this topic (Biering-Sørensen et al. 2018; Squair et al. 2015; Teasell et al. 2000).

In addition to changes in cardiovascular function and control, SCI also impacts metabolic function. People with SCI experience accelerated risk for accumulating adipose tissue (Buchholz & Bugaresti, 2005; Chen et al. 2006; Cirnigliaro et al. 2015; Farkas et al. 2019; Gorgey & Dudley, 2007; Gorgey et al. 2018; Gorgey & Gater, 2011b, 2011c; Gorgey et al. 2011; Groah et al. 2009; Liang et al. 2007; Spungen et al. 2003; Spungen et al. 2000; Wen et al. 2019) and developing lipid (Brenes et al. 1986; Ellenbroek et al. 2014; Emmons et al. 2010; Karlsson et al. 1995a; La Fountaine et al. 2018; La Fountaine et al. 2017; Maki et al. 1995; McGlinchey-Berroth et al. 1995; Nash et al. 2005; Zlotolow et al. 1992) and glucose (Aksnes et al. 1996; Battram et al. 2007a; Bauman et al. 1999; Chilibeck et al. 1999b; Duckworth et al. 1983a; Duckworth et al. 1980; Elder et al. 2004; Gorgey & Gater 2011a; Jeon et al. 2002; Karlsson et al. 1995b; Lewis et al. 2010; Palmer et al. 1976; Segal et al. 2007; Wang et al. 2009; Yarar-Fisher et al. 2013b) metabolic disorders. The disease outcomes of these, and other, metabolic changes can be categorized as cardiometabolic disease (CMD). The Consortium for Spinal Cord Medicine (CSCM) recently released Clinical Practice Guidelines for CMD in SCI (Nash et al. 2019a). These guidelines are the first to establish SCI-specific diagnostic criteria for the cluster of risk factors that coalesce as CMD, as well as population-specific management strategies. Obesity is the most prevalent CMD risk factor in the SCI population (Libin et al. 2013; Nash et al. 2019b), with a CMD body mass index (BMI) cut-off ≥22 kg/m^2. The SCI-specific BMI cut-off (≥22 kg/m^2 vs 30 kg/m^2) is required due to dysregulation of muscle (Crameri et al. 2002; Ditor et al. 2004; Duffell et al. 2008; Gorgey et al. 2020; Grimby et al. 1976; Shields 1995; Stewart et al. 2004a; Talmadge, Castro, et al. 2002; Talmadge, Roy, et al. 2002), bone (Carpenter et al. 2020; Gorgey et al. 2013; Minaire et al. 1984; Zleik et al. 2019), and adipose (Buchholz & Bugaresti 2005; Chen et al. 2006; Cirnigliaro et al. 2015; Farkas et al. 2019; Gorgey & Dudley 2007; Gorgey et al. 2018; Gorgey & Gater 2011b, 2011c; Gorgey et al. 2011; Groah et al. 2009; Liang et al. 2007; Spungen et al. 2003; Spungen et al. 2000; Wen et al. 2019) tissue that results in greater adiposity per unit mass. For example, a recent study of seventy-two participants with chronic motor complete SCI showed that a BMI of 27.3 kg/m^2 corresponded with a body fat percentage of 42 % (Gater et al. 2021), a much higher body fat percentage than would be expected for a person without SCI and a BMI <30 kg/m^2. Insulin resistance, or diabetes, uses a cut-off of fasting blood glucose ≥100 mg/dL, the same value as used in persons without SCI. However, it should be noted that laboratory tests for insulin resistance (Aksnes et al. 1996; Duckworth et al. 1980; Jeon et al. 2002; Karlsson et al. 1995b; Palmer et al. 1976) and oral glucose tolerance (Aksnes et al. 1996; Battram et al. 2007b; Bauman et al. 1999; Chilibeck et al. 1999a; Duckworth et al. 1983b; Duckworth et al. 1980; Elder et al. 2004; Gorgey & Gater, 2011a; Jeon et al. 2002; Karlsson et al. 1995b; Lewis et al. 2010; Segal et al. 2007; Wang et al. 2009; Yarar-Fisher et al. 2013a) have routinely found that persons with SCI who have “normal” fasting blood glucose (<100 mg/dL) are likely to have impaired glycemic regulation (Aksnes et al. 1996; Bauman et al. 1999; Gorgey & Gater, 2011a; Lewis et al. 2010; Segal et al. 2007; Wang et al. 2009). Dyslipidemia has two cut-off criteria: (1) blood triglyceride (TG) concentration ≥ 150 mg/dL, and (2) blood high density lipoprotein cholesterol (HDL-C) concentration of ≤ 40 and ≤ 50 mg/dL for men and women, respectively. The TG concentration cut-off is similar to CMD cut-offs used for people without SCI, but the HDL-C cut-off is population-specific due to the highly reproducible finding of low HDL-C in SCI (Bauman et al. 1992; Gilbert et al. 2014; Krum et al. 1992; La Fountaine et al. 2018; Liang et al. 2007; Lieberman et al. 2014; Washburn & Figoni 1999). Finally, a hypertension cut-off for blood pressure is also similar to that of the general population (≥ 130 and 85 mmHg for systolic and diastolic blood pressure, respectively). However, as mentioned above, especially in high-level SCI blood pressure can be low for neurogenic reasons that confounds the use of this outcome to reflect cardiovascular disease risk.

Whilst changes in neural control following injury are extremely hard to alter, physical activity and/or exercise can act as a powerful disease modifying intervention. Evidence-based guidelines have established the use of physical activity to increase cardiorespiratory fitness and muscular strength in persons with SCI (Martin Ginis et al. 2011). More recently, the CSCM CMD guidelines recommend physical exercise as a primary treatment strategy for the management of CMD in SCI. Furthermore, AGREE II evidence-based activity guidelines (Martin Ginis et al. 2011) were recently updated (Martin Ginis et al. 2018) and state with moderate to high confidence that exercise benefits CMD in persons with SCI (Martin Ginis et al. 2018). Yet despite this, individuals with SCI continually self-report some of the lowest levels of activity among any population in society. In the present chapter we review the effect various forms of exercise and/or physical activity have on cardiovascular and metabolic function in individuals with chronic SCI. In reviewing each exercise/physical activity modality/intervention we critically evaluate the strength of the evidence underlying the findings. Although we will use physical activity and/or exercise interchangeably throughout this chapter it is important to note that physical activity is any form of movement that elicits an increase in energy expenditure, whereas exercise is a program of planned and specific physical activity that specifically targets a desired outcome. It is also important to note that “exercise” is used in a separate context from the type of “rehabilitation exercises” commonly employed by allied-health therapists in a rehabilitation context (where the goal is to augment specific neuromotor function). The vast majority of studies in the field of SCI have investigated the effect of exercise on cardiometabolic function.

3 Cardiovascular Health and Endurance

3.1 Cardiorespiratory Fitness and Endurance

Cardiorespiratory fitness is a broadly encompassing term used as a measure of aerobic fitness, and provides an overall indication of how well the lungs, heart and muscle are able to work together to uptake oxygen from the environment and utilize it to perform work. The most common indicator of cardiorespiratory fitness is VO_2peak, which represents the peak capacity to uptake and utilize oxygen during a given form of exercise. In able-bodied individuals VO_{2peak} is negatively related to the risk for all-cause mortality (i.e., higher the VO_{2peak} the less mortality) and the onset of CMD. Although there is not long-term data yet available for the field of SCI, it is likely that the same relationship between VO_{2peak} and risk for CMD exists, especially in those with lower-level and/or incomplete injuries. Changes in cardiorespiratory fitness has been examined in response to various forms of exercise including body-weight supported treadmill training, arm cycle exercise, functional electrical stimulation exercise, and hybrid exercise (i.e., stimulation of the lower limbs and active arm-exercise). Each of these will now be reviewed.

3.1.1 Arm Cycle Ergometry (ACE) Training

Arm cycle ergometry (ACE) is a mode of rhythmic exercise where the arms are used to spin an axle-and-crank system that is similar to a stationary bicycle but for upper extremity use. Usually, the exerciser remains in their chair, with the ergometer placed on a table. Another approach is to fix the ergometers to a wall or other vertical structure. If an ergometer is intended to be used by more than one person, it is important that the height of the device is adjustable to accommodate different statures and wheelchairs (and thus different heights of the apex of the shoulders). These ergometers are most often used to achieve sustained, endurance-type exercise targeting increases in VO_2 and HR. However, testing and training of muscular power production can also be achieved via sprint-type cycling. Arm ergometers can be simple to construct and thus, in theory, should be relatively inexpensive and accessible. They are general conditioning tools, but their transferability to real-world tasks is somewhat limited. Furthermore, it is generally thought that the movement pattern is sub optimal for the upper extremities and thus there could be an increased risked for overuse injuries using this mode of exercise. Other rhythmic upper-extremity exercise devices have been developed to address this concern, such as the Vitaglide. Despite these shortcomings, arm ergometry is commonly employed mode of exercise due to simplicity of the equipment and the predictability of the physiological response.

Table 1. Effect of Arm Cycle Ergometry Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Graham et al. (2019) USA RCT	Population: Gender: males=6, females=1; Mean time since injury: >3 yr. *Intervention group:* Mean age: 49.4±13yr; Level of	1. No effect VO_{2peak} 2. Time effect for QUICKI. 3. There was a significant effect of time on muscle

PEDro=5 $N_{Initial}$=9, N_{Final}=7	injury: C6=1, C8=1, T8=1, L1=1; Level of severity: AIS A=1, B=3. *Control group:* Mean age: 51.3±1.2yr; Level of injury: C7=1, T6=1, T8=1, T12-L1=1; Level of severity: AIS A=1, B=1, D=1. Intervention: Subjects were randomly allocated to either the intervention group or the control group. The intervention group participated in 6 wk high-intensity interval training (HIIT), whereas the control group performed moderate-intensity training (MIT). Both groups performed training on an arm ergometer. The intervention group trained for 20min, 2x/wk, whereas the control group trained for 30 min, 3x/wk. Both groups trained for 6wk. Assessments were taken at baseline, and post-intervention. Outcome Measures: fat mass, lean mass, percent body fat, percent arm fat, percent leg fat, blood pressure, resting energy expenditure, oral glucose tolerance test, quantitative insulin sensitivity check index (QUICKI), blood lipids, strength assessment, peak oxygen uptake, peak power on ergometer.	strength in the chest press (0.035) and latissimus pulldowns (p=0.021) exercises. Additionally, there was a significant interaction effect for chest press in favour of MIT. 4. Almost all patients ↓ in total cholesterol and LDL, whereas changes in serum triglycerides and HDL were variable.
Kim et al. (2015) Korea RCT PEDro=5 N=15	Population: 15 participants (9 males, 6 females) with SCI (ASIA-A &B, C5-T11). Mean age was 33 and all participants had SCI for more than 6 months. 8 participants allocated to the hand-bike exercise group, 7 participants to the control group. Intervention: Participants exercised with the indoor-hand bike for 60min/day, 3 days/week, for 6 weeks under supervision of	1. The exercise group ↑ in $V0_{2peak}$ and upper body strength compared with the control group following intervention. 2. Post-intervention, the exercise group showed significant ↓ HOMA-IR levels compared with the control group. 3. The exercise group exhibited significantly lower insulin and HOMA-

	an exercise trainer. Participants maintained a heart rate of 70% of their maximum. Exercise intensity was gradually ↑ on a weekly basis using the Borg rating of perceived exertion (RPE level 5 to 7). The control group continued with usual activities. Outcome Measures: Body mass index (BMI), waist circumference, percent body fat, insulin level, homeostasis model assessment of insulin resistance (HOMA-IR) level, upper body muscle strength (using a dynamometer), VO_{2peak}, lipid metabolite indices (including cholesterol, triglycerides, high & low density lipoprotein cholesterol levels.	0R levels, and ↑ in high density lipoprotein cholesterol after the exercise training period compared with baseline levels. 4. No change in glucose, total cholesterol, triglycerides, or low density lipoprotein were observed in the exercise group.
Rosety-Rodriguez et al. (2014) Spain RCT PEDro=7 N=17	Population: *Experimental group:* Mean age: 29.6±3.6yr; Time post injury: 54.8±3.4mo. *Control group:* Mean age: 30.2±3.8yr; Mean time since injury: 55.7±3.6mo. Gender: males=17, females=0; Level of injury: T2-L5=17. Intervention: 12wk arm cranking exercise program for 3 sessions/wk. Each training session consisted of warm-up (10-15min), arm crank (20-30min; increasing 2min and 30sec every 3wk) at a moderate work intensity of 50% to 65% of heart rate reserve (starting at 50% and increasing 5% every 3wk), and cool-down (5-10min). Control participants completed assessments but did not take part in a training program. The control group consisted of individuals matched for age, sex, and injury level.	1. ↑ VO_{2peak} in the intervention group ($p=0.031$). 2. Leptin, TNF-a and IL-6 levels were significantly ↑ in the exercise group ($p<0.05$) when compared to the control after the exercise intervention. 3. All other measures were not significantly different between the two groups ($p>0.05$)

	Outcome Measures: Plasma levels of leptin, adiponectin, plasminogen activator inhibitor-1 (PAI-1), TNF-a, IL-6, maximum oxygen consumption [VO_{2peak}], anthropometric index [AI], waist circumference [WC], and body mass index [BMI].	
Ordonez et al. (2013) Italy RCT PEDro=8 N=17	Population: *Intervention group* (n=9): mean age: 29.6yr; Gender: males=9, females=0; mean time post injury: 54.8mo. *Control group* (n=8): mean age: 30.2yr; Gender: males=8, females=0; mean time post injury: 55.7mo; At or below the fifth thoracic level (T5). Intervention: Intervention group performed a 12-week arm-cranking exercise program, 3 sessions/wk, consisting of warming-up (10-15min) followed by a main part in arm-crank (20-30min [increasing 2min and 30s every 3wk]) at a moderate work intensity of 50% to 65% of the HR reserve and by a cooling-down period. Outcome Measures: Plasmid levels of total antioxidant status, erythrocyte glutathione peroxidase activity malondialdehyde and carbonyl group levels, physical fitness and body composition.	1. When compared with baseline results, VO_{2peak} was significantly ↑ in the intervention group. 2. Both total antioxidant status and erythrocyte glutathione peroxidase activity were significantly ↑ at the end of the training program. 3. Plasmatic levels of malondialdehyde and carbonyl groups were significantly reduced following training.
Jacobs et al. (2009) USA RCT PEDro=5 N=18	Population: Traumatic SCI: RT Group: Mean age: 33.7±8.0yr; Gender: males=6, females=3; Mean body mass: 72.3±18.3 kg: ET group: Mean age: 29.0±9.9yr; Gender: males=6, females=3; Mean body mass: 83.7±8.9kg.	1. Significant effects of both modes of training (RT and ET) in the physiological responses to $VO2_{peak}$ GXT were observed. 2. Muscular strength significantly ↑ for all

	Intervention: Subjects participated in a series of testing sessions before and after a 12wk training period. Patients were randomly assigned to two groups. The endurance training (ET) group performed 30 min of arm cranking exercise using a Saratoga arm crank device during each session at 70%–85% of HR_{peak}. The resistance training (RT) group performed three sets of 10 repetitions at six Hammer Strength MTS exercise stations (including horizontal press, horizontal row, overhead press, overhead pull, seated dips, and arm curls) with an intensity ranging from 60% to 70% of 1 repetition maximum (1RM). Outcome Measures: VO_{2peak}, Graded exercise test (GXT); assessed at baseline and at end of treatment (12 wks).	exercise maneuvers in the RT group with no changes detected in the ET group 3. VO_{2peak} values were significantly greater after RT (15.1%) and ET (11.8%). 4. Both RT and ET study groups displayed significant ↑ in PO_{peak} and PO_{mean}. 5. Mean power ↑ 8% and 5% for the RT and ET groups, respectively, with no statistically significant differences apparent between groups. RT produced significantly greater gains in PO_{peak} (15.6%) compared with ET (2.6%). 6. The RT group displayed significantly ↑ strength values ranging from 34% to 55% for the six exercise maneuvers. In contrast, the ET group did not display ↑ in muscular strength for any of the six exercises after 12wk of training.
Brizuela et al. (2020) Spain Pre-Post N=11	Population: Mean age: 36.5±10.0yr; Time since injury: 13.1±9.9yr; Injury etiology: traumatic SCI; Level of injury: C4-7; Level of severity: AIS A=8; AIS B=3. Intervention: Individuals were divided into two groups: higher or lower CSCI. They underwent an 8wk stationary arm-crank exercise (ACE) training program twice/wk. Training was performed on a stationary and mechanically-braked pedaling machine, modified and	1. ↑ PO_{peak} in both groups ($p<0.05$), whereas maximum voluntary ventilation (MVV) and low frequency HRV (LF) improved only in the lower CSCI group ($p<0.05$). 2. QIF and PO_{peak} were significantly correlated before ($r=0.88$; $p<0.01$) and after ($r=0.86$; $p<0.01$) the training period.

	converted to an adapted arm-crank machine. Outcome Measures: Quadriplegia index of function (QIF) questionnaire, Fukuda Sangyo ST-250 spirometer, Borg CR10 scale.	
Williams et al. (2020) Canada Pre-Post N=14	Population: Gender: males=8, females=6; mean age=44.3yr; level of injury: C4=1, C5=2, C6=1, C7=1, T4=2, T5=1, T8=1, T11=1, T12=2; level of severity: AIS A=6, B=5, C=2, D=1; time since injury ≥1yr. Intervention: participants took part in a 5wk at 3 sessions/wk of arm crank ergometry (ACE) training protocol which featured modulations in cadence and resistance, as well as back supported and unsupported bouts. Outcome Measures: Changes in aerobic capacity (peak oxygen consumption) and seated balance control (centre of pressure parameters).	1. ↑ VO_{2peak} by an average of 16% following training (p=.005). 2. Unsupported ACE was effective for eliciting trunk muscle activity (p<0.05). 3. Static sitting balance significantly improved from pre to post intervention, but only when tested with eyes closed as a measure by a reduction in area (p=.047) and velocity of centre of pressure (p=.013). 4. No significant changes were observed in static sitting balance with eyes open, or in dynamic sitting balance.
Bresnahan et al. (2019) USA Pre-Post $N_{Initial}$=10, N_{Final}=6	Population: Age: 36.7±12.5yr; Gender: males=8, females=2; Level of injury: cervical=3, thoracic=7; Severity of injury: AIS A=8, AIS B=2; Mean time since injury: 12.4yr. Intervention: Arm crank ergometry (ACE) 30 min/day, 3 days/wk for 10 days at 70% VO_{2peak}. Outcome Measures: VO_2, respiratory quotient (RQ), graded exercise testing (GXT) time, $_{peak}$ power, heart rate, energy expenditure (EE), time to traverse a 100ft-5° ramp, 12-min wheelchair propulsion test, body composition (% fat mass;	1. Post intervention there was significant improvement in resting VO_2 (p=0.046), VO_{2peak} (p=0.028), PO_{peak} (p=0.026), RQ (p=0.028), and 12-min wheelchair propulsion test (p=0.028). 2. There was no significant improvement post intervention in GXT time, HR_{peak}, EE, and time to traverse a 100ft-5° ramp. 3. There was no significant difference in any body composition or lipid profile measures post-intervention.

	bone mineral content; bone mineral density; fat mass; lean body mass), metabolic profile (%Beta cell activity; %insulin sensitivity; high-density lipoprotein-cholesterol; HOMA: homeostasis modeal assessment (HOMA); Insulin sensitivity index; low-density lipoprotein-cholesterol; triglycerides; fasting glucose to insulin ratio).	4. Fasting insulin ($p=0.028$), fasting glucose to insulin ($p=0.028$), and HOMA %insulin sensitivity ($p=0.046$) which improved.
Horiuchi & Okita, (2017) Japan Pre-Post N=9	Population: Mean age: 38±10yr; Gender: males=9, females=0; Level of injury: T8-L1=9; Level of severity: AIS A=7, AIS B=2; Mean time since injury: 16±7.1yr. Intervention: Individuals with a SCI) performed 2 × 30 min sets of arm-cranking exercises with a 10 min resting interval between them, 4 days/wk for 10 wk at an intensity of 50~70% heart rate reserve (HRR). Outcome Measures: Isometricmaximum handgrip (HG), strength, body mass (BM), waist circumference (WC), aerobic capacity ($VO_{2\ peak}$), plasminogen activator inhibitor 1 (PAI-1), systolic blood pressure (SBP), glucose metabolism, and lipid profiles (triglycerides (TG), high-density lipoprotein (HDL) cholesterol).	1. ↑ VO_{2peak} with the 10-week arm-cranking exercise training ($p<0.05$). 2. After the 10-week detraining phase, WC, BM, VO_{2peak}, SBP, TG, and PAI-1 accurately recovered with statistical differences between post-training and detraining ($p<0.05$). 3. Spearman rank order analysis revealed that changes in PAI-1 were related to changes in VO_{2peak}, BM, WC, TG, and HDL cholesterol. 4. Multiple linear regression analysis revealed that WC was the most sensitive factor for predicting changes in PAI-1 ($p=0.038$).
Valent et al. (2010) Netherlands Longitudinal cohort study N=20	Population: *Experimental Group (n=17):* Mean age=46yr; Gender: male=13, female=4; Level of injury: 10=paraplegia, 7=tetraplegia; Control *Group (n=17):* Mean age= 40yr; Gender: male=13, females=4; Level of injury:11=paraplegia, 6=tetraplegia. Intervention: Experimental subjects received hand cycle	1. No significant effect of hand cycle training was found for $V0_{2peak}$. After correction for body mass, again a trend ($p=0.070$) was found for PO_{peak} (W/kg), but no effect was found on $V0_{2peak}$ (ml/min/kg). 2. Although no significant effect of hand cycle

	training in addition to regular care and the control subjects only received regular care. Individuals with paraplegia started the hand cycle training programme at the start of active rehabilitation and those with tetraplegia started 3 months later. Both continued training twice/wk until discharge. The duration of training sessions was between 35 and 45 min. The pre- and post-test outcomes of the experimental subjects were compared with the pre- and post-test outcomes of the matched control subjects. Outcome Measures: peak power output (PO$_{peak}$), peak oxygen uptake (V0$_{2peak}$), oxygen pulse, isometric peak muscle strength of the upper extremities, pulmonary function.	training was found for the training versus control group on the outcome measures of wheelchair capacity, positive trends were found for wheelchair PO$_{peak}$ and oxygen pulse with p-values of 0.079 and 0.052, respectively 3. Significantly larger improvements were found in the experimental group compared to the control group for muscle strength of elbow flexion (only left), internal and external rotators of the shoulder (both left and right). No training effect was found for the other muscle groups. 4. No significant training effects of hand cycling were found for pulmonary function. 5. Comparing pre- with post-test results in the training group only, there were substantial improvements in PO$_{peak}$ ($p<0.001$), but only a trend for improvement in V0$_{2peak}$ ($p=0.065$).
Valent et al. (2009) Netherlands Pre-Post N=22	Population: Mean age: 39yr.; Gender: males=18, females=4; Level of injury: C5-T1=22; Mean time post injury: 10yr. Intervention: Participants completed a total of 24 sessions of hand cycle interval training program within a continuous period of 8-12wk. The duration of one training session was between 35-45min. During training, participants	1. The VO$_{2peak}$ significantly improved, on average, 114 mL*min^{1} (SD=204) after training, which was an ↑ of 8.7% (SD=13.9%). In addition, a significant improvement in PO$_{peak}$ of 8.3 W (SD=5.8) was found after training, which was an ↑ of 20.2% (SD=15.0%). 2. Mean peak respiratory exchange ratio was 1.10 in

	wore heart rate monitors and were expected to train at 60% to 80% of heart rate reserve (HRR). Rating of perceived exertion (RPE) was monitored using the Borg 10-point scale and was intended to range from 4 to 7. Outcome Measures: peak power output (PO_{peak}), peak oxygen uptake ($V0_{2peak}$), peak muscle strength (force-generating capacity) of the upper extremities, respiratory function, participant-reported shoulder pain.	both the pre-test and the post-test, suggesting that, in general, $V0_{2peak}$ was reached. 3. No significant improvement in O_2P (mean difference=1.3 mL*beat^1, SD=0.2) (p=.06) was seen in the pretraining-post training comparison. As expected, HR_{peak} did not change between pretraining (X=128 b*min^1, SD=24) and post training (127 b*min^1, SD=27). A significant ↓ in $V0_2$submax during hand cycling of 73 mL*min^1 (SD=122) (X=8.8%, SD=14.6%) (p=.04) was found at a constant power output, indicating improved gross mechanical efficiency during hand cycling. 4. Only shoulder abduction strength significantly improved (X=5.6%, SD=11%). 5. No effects of hand cycle training were found on pulmonary function outcome measures.
El-Sayed et al. (2005) UK Pre-Post N=12	Population: 5 SCI, lesion below T10, age 32yr; 7 AB controls, age 31yr. Intervention: Arm ergometry, 30 min/d (60%–65%VO_{2peak}), 3 d/wk, 12 wks. Outcome Measures: VO_{2peak}, HR_{peak}, workload, total cholesterol (TC), triglycerides, HDL.	1. (Results repeated from 2004 paper) 2. Training improved HDL but did not alter TC or triglycerides.

El-Sayed et al. (2004) United Kingdom Pre-Post N=12 (N=5 SCI)	Population: *SCI Group:* Mean age: 32.0±1.6yr; Gender: males=5, females=0; Level of injury: <T10=5. *Able-Bodied Group:* Mean age: 31.0±2.9yr. Intervention: Arm ergometry, 30 min/day (60%– 65%VO_{2peak}), 3 days/wk, 12wk. Outcome Measures: Oxygen consumption (VO_{2peak}), heart rate (HR_{peak}), work load (WL_{peak}), platelet aggregation.	1. ↑ VO_{2peak}, lower heart rate, and greater work load among normal subjects compared to those with SCI ($p<0.05$ for all). 2. There were no significant differences in platelet aggregation post intervention for either group, or between groups.
Silva et al. (1998) Brazil Pre-Post N=24	Population: N=24 participants (12 people with paraplegia, 12 able-bodied individuals), median age SCI: 31yr (range 22-54), control: 30 (range 22-52), T1-T12, all ASIA A, >3yr after injury. Intervention: Arm cranking aerobic training: 30 mins, 3x/wk x 6 wks. Outcome Measures: Spirometry.	1. After aerobic training, SCI participants showed significant ↑ in FVC and the ventilatory muscle endurance, so that peak voluntary ventilation at 70% time values post-training were not different from the initial values of able bodied individuals. 2. Severely limited ventilatory muscle endurance in people with paraplegia can be improved by arm cranking.
DiCarlo et al. (1988) USA Pre-Post N=4	Population: Mean age: 24.3yr; Gender: males=4; Injury etiology: traumatic SCI=3, congenital SCI=1; Level of injury: C5-7=3, T7-8=1. Intervention: Individuals completed pre and post training maximal exercise testing, which consisted of noncontinuous, multistage graded arm ergometry. Training sessions were 30min ACE, 3 times/wk for 5wk at an intensity of 60-80% of HR_{peak}. Heart rates, maximal work loads and oxygen consumption (VO_{2peak}) were measured.	1. VO_{2peak} significantly ↑ from pretraining to post training ($p<0.05$). 2. Maximal work loads did not ↑ significantly from pretraining to post training ($p>0.05$).

	Outcome Measures: Daniel's one-way respiratory valve, Parkinson-Cowan Dry Gas Meter, Beckman E_2 Oxygen Gas Analyzer, Goddart KK Capnograph, Modified V5 chest lead, Hewlett Packard oscilloscope.	
McLeod et al. (2020) Canada RCT PEDro=6 N=20	Population: *MICT Group (n=10):* Mean age=45yr; Gender: males=5, females=5; Level of injury: C2-C7, T8-L4; Mean time post injury=56 days; *SIT Group (n=10):* Mean age= 47yr.; Gender: male=10, female=0; Level of injury: C2-C4, T7-L2; Mean time post injury=72 days. Intervention: Participants were randomized to SIT or moderate-intensity continuous training (MICT). SIT consisted of 3 × 20 sec "all-out" (>100% peak power output) arm-cycle sprints interspersed with 2 mins of active recovery (10% $_{peak}$ power output; total time commitment, 10 mins). MICT involved 20 mins of arm-cycling (45% $_{peak}$ power output; total time commitment, 25 mins). Both training interventions were delivered 3 times/wk for 5wk. peak power output, sub-maximal exercise performance and exercise self-efficacy were assessed at baseline (pre-training) and 72 h following the final training session (post-training). Outcome Measures: Heart rate (HR), Borg's Rating of Perceived Exertion (RPE), peak power output (PO_{peak}), maximal and sub-maximal power outputs, exercise enjoyment, exercise self-efficacy, and pain.	1. PO_{peak} ↑ by 39% (95% CI: 18, 60) for SIT, and 33% (95% CI: 15, 50) for MICT, with no significant difference between groups (mean group difference: 6%; 95% CI: −19, 31; p=0.524). 2. Exercise workload during the SIT and MICT corresponded to 154%, and 64% of PO_{peak} achieved at pre-training, respectively. Over the course of the 5 weeks of training, the average volume of exercise performed during SIT was lower than MICT (13 ± 8 kJ vs 37 ± 16 kJ). 3. Improvements in PO_{peak} were not different across persons with paraplegia or tetraplegia. 4. Compared to the MICT group, mean HR, central RPE, and peripheral RPE were significantly ($P<0.05$) higher for the SIT group across exercise sessions. 5. There were no between-group differences in power output achieved across a range of submaximal workloads. 6. There were no between-group differences in exercise enjoyment,

		changes in exercise self-efficacy, and pain.
Nightingale et al. (2017) U.K. RCT PEDro=5 $N_{Initial}$=24,N_{Final}=21	Population: *Control Group (n=8):* Mean age: 48±10yr; Gender: males=6, females=2; Level of injury: T4–L3 (≤T6=4, ≥T6 =4); Level of severity: AIS A-B=7, AIS C-D=1; Mean time since injury: 20±10yr; Intervention Group (n=13): Mean age: 46±6yr; Gender: males=9, females=4; Level of injury: T4–L1 (≤T6=4, ≥T6=4; Level of severity: AIS A-B=11, AIS C-D=2; Mean time since injury: 14±11yr Intervention: Participants were randomized into either a 6wk prescribed home-based exercise intervention (INT) or control group (CON). Participants allocated to the exercise group completed four, 45 min moderate-intensity (60-65% VO_{2peak} oxygen uptake (VO_{2peak}) arm-crank exercise sessions/wk. Outcome Measures: Physical activity energy expenditure, Body composition, Metabolic regulation, VO_{2peak}, power output, Homeostasis Model Assessment of Insulin Resistance (HOMA2-IR), Fasting and postprandial concentrations of plasma glucose and serum insulin.	1. The INT group significantly ↑ (p<0.001) VO_{2peak} and PO_{peak}, whereas these outcomes remained unchanged in the CON group. 2. The moderate-intensity upper-body exercise INT group significantly ↑ physical activity energy expenditure and minutes spent performing moderate-to-vigorous intensity physical activity relative to the CON group (p<0.01). 3. Changes in fasting serum insulin concentrations and HOMA2-IR were different between the two groups (p<0.044). The INT group significantly ↓ fasting serum insulin concentrations and HOMA2-IR (p<0.035), whereas these outcomes were unchanged in the CON group. 4. Fasting plasma glucose and outcomes derived following an oral glucose tolerance test (post-load responses indicative of peripheral insulin resistance) were not significantly different over time (all P >0.6), with no interaction effects (all P >0.3)

de Groot et al. (2003) Netherlands RCT PEDro=7 N=6	Population: 4 male, 2 female, C5-L1, AIS A (*n* = 1), B (*n* = 1), and C (*n* = 4), age 36yr, 116 d post-injury. Intervention: Randomized to ACE low-intensity (LI: 40%–50% HRR) or high-intensity (HI: 70%–80% HRR) arm ergometry. The 1 h interval training consisted of 3 min exercise bouts interspersed with 2 min of rest 3 d/wk, 8wk. Outcome Measures: VO_{2peak}, peak power output, insulin sensitivity (HOMA-CIGMA test), blood glucose and lipid profile (total cholesterol, high-density lipoprotein cholesterol, high-density lipoprotein cholesterol and triglycerides).	1. ↑ in VO_{2peak} and PO_{peak} for the group as a whole (P<0.05). 2. VO_{2peak} ↑ significantly more, and triglycerides and TC/HDL ratio ↓ significantly more in the HI group than in the LI group (P=0.05). 3. There was a significant difference in insulin sensitivity between groups (P = 0.05), with a non-significant decline in the HI group and a nonsignificant improvement in the LI group with training. 4. The ↑ in PO_{peak} and the changes in lipid profile parameters TC, HDL and LDL did not differ between the two groups. 5. A positive correlation was observed between VO_{2peak} and insulin sensitivity (*r* = 0.68, *p* = 0.02).

Discussion

There is strong, level 1a evidence, from three RCT studies showing that arm cycle ergometry (ACE) training, 3 sessions per week for 8-12 weeks results in increased cardiorespiratory fitness (as assessed by peak rate of whole-body oxygen consumption during exercise). Further moderate evidence, two level 1b RCTs, and weak evidence, from five pre/post studies, corroborate the beneficial effect of ACE on cardiorespiratory fitness with 2 to 4 sessions per week for as little as 2 to as many as 16 weeks. In fact, only two of the 18 studies included in the above table suggest no effect of ACE on cardiorespiratory fitness. There is also solid evidence for benefit of ACE on endurance. There are two level 1a RCTs, two level 1b RCTs, and three level 4 pre/post studies providing evidence that ACE can benefit a component on endurance performance in people with SCI. This robust evidence-base for the effect of ACE training on cardiorespiratory fitness and endurance are well established, and are a large part of the foundation of the existing SCI physical activity guidelines mentioned in the introduction.

Conclusion

Ordonez et al (2013) provided Level 1 evidence that 12 wk of 3 day/wk of ~45 min benefits VO_2peak.

Rosety-Rodriqguqez et al (2014) provided Level 1 evidence that 12 wk of 3 day/wk of ~45 min ACE benefits VO_2peak.

McLeod et al (2020) provided Level 1 evidence that 5 wk of 2 day/wk of ACE benefits VO_2peak.

Nightingale et al (2017) provided Level 2 evidence that 6 wk of 3 day/wk of ACE benefits VO_2peak and PO_{peak}.

Graham et al (2019) provided Level 2 evidence that 6 wk of 2 day/wk of on ACE benefits strength.

Kim et al (2015) provided Level 2 evidence that 6 wk of 3 day/wk of 60 min ACE increases VO_2peak and strength.

Jacobs et al (2009) provided Level 2 evidence that 12 wk of 2 day/wk of 20 min ACE benefits VO_2peak and PO_{peak}.

Brizuela et al (2020) provided Level 4 evidence that 8 wk of 2 day/wk of ACE benefit PO_{peak}.

Williams et al (2020) provided Level 4 evidence that 5 wk of 3 day/wk of ACE benefits VO_2peak.

Bresnahan et al (2019) provided Level 4 evidence that 2 wk of 3 day/wk of ACE benefits VO_2peak and PO_{peak}.

Horiuchi and Okita (2017) provided Level 4 evidence that 10 wk of 4 day/wk of ACE benefits VO_2peak.

Valent et al (2010; Valent et al. 2009) provided Level 4 evidence that 8-12 wk of 2 day/wk of ACE benefits VO_2peak, PO_{peak}, and some measures of strength.

El-Sayed et al (2004) and El-Sayed and Younesian (2005) provided Level 4 evidence that 12 wk of 3 day/wk of ACE benefits VO_2peak.

Silva provided is Level 4 evidence that 6 wk of 3 day/wk of ACE benefits pulmonary function.

DiCarlo (1988) provided Level 4 evidence that 5 wk of 3 day/wk of ACE benefits VO_{2peak}.

De Groot et al (2003) provided Level 4 evidence that 8 wk of 3 day/wk of ACE benefits VO_2peak and PO_{peak}.

3.1.2 Wheelchair Propulsion Training

The propulsion, or “pushing”, of a manual wheelchair can be used as a form of exercise. There are multiple approaches to perform such exercise, including simple over-ground pushing (as is used for mobility / locomotion) or the use of devices that allow for stationary pushing. The most common devices are roller systems that the wheelchair’s rear wheels are placed over, and that allow for power output to be modulated by controlling the amount of rotational resistance on the rollers. Less common are wheelchair-compatible treadmills. These devices are usually large, require different belts than running treadmills, and are often outfitted with catch systems so that users do not roll off the back of the device during use. It should be noted that if a person’s primary means of mobility/locomotion is wheelchair propulsion, the additional repetitions of this approach during exercise is likely to increase risk for upper extremity over-use injury. Conversely, if the person’s primary means of mobility is an electric wheelchair then there can be a considerable learning effect with wheelchair pushing on a treadmill and/or rollers.

Table 2. Effect of Wheelchair Propulsion Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Keyser et al. (2003) USA Pre-post N=27	Population: Mean age: 41±10yr; Gender: males=20, females=6. Intervention: Individuals completed wheelchair ergometer tests using a 1min JUMP protocol that resulted in volitional exhaustion in 6-12min. They underwent 12wk of simulated wheelchair rolling exercise using elastic straps positioned to mimic the motion of propulsion. JUMP	1. No significant differences in VO_{2peak}, anaerobic threshold, or $_{peak}$ HR were observed at 6-12 weeks of the training program ($p>0.05$). 2. Substantial improvement in peak constant work rate tests time was noted at 6 and 12wk ($p<0.001$), with no significant difference between 6 and 12wk and no significant intergroup difference ($p>0.05$).

	and constant work rate tests were performed before training and after 6 and 12wk of exercise. Outcome Measures: HR monitor, EKG electrodes, Microprocessor, Pneumotachometer.	
Le Foll-de Moro et al. (2005) France Pre-Post N=6	Population: Mean age: 29±14yr; Mean time since injury: 94±23 days; Gender: males=5, females=1; Level of injury: T6-12. Intervention: Spirometric values at rest and dynamic ventilatory responses were studied before and after the wheelchair propulsion training program. The training program consisted of three 30 min exercise sessions/wk for 6 weeks including 6 successive work bouts 5 min each. During each work bout, a 4 min period of moderate work (base) was followed by a 1 min period of intense work (peak). Initially, the base was set at 50% of the maximal tolerated power obtained in the initial maximal exercise test, and the peak was set at 80%. The intensity of each training session was designed to lead up to almost 80% of maximal heart rate at the end of the sixth peak. Outcome Measures: Spirometric test, Breath-by-breath gas analyzer system, ECG, Telemetry.	1. Vital capacity (VC) (Δ3%), forced expiratory volume in 1 sec (FEV_1) (Δ7.1%), peak expiratory flow rate (PEFR) (Δ7.6%), and ratio FEV_1/VC (4.1%) showed small positive change, which was not statistically significant ($p>0.05$). 2. Maximal tolerated power (MTP) and VO_{2peak} significantly ↑ after training ($p<0.05$). 3. At maximal exercise, there was a non-significant improvement in peak ventilation (V_{Epeak}), peak tidal volume (VT_{peak}), peak breathing frequency (F_{peak}), and ventilatory reserve after training ($p>0.05$). 4. Oxygen cost of V_E ↓ significantly after training ($p<0.05$). 5. At the same workload after training, V_E and f significantly ↓ and VT significantly ↑ ($p<0.05$).
Bougenot et al. (2003)	Population: Mean age: 35±13yr; Gender: males=7;	1. Maximal tolerated power (MTP), VO_{2peak}, and VCO_{2peak}

France Pre-Post N=7	Level of injury: T6-L5; Level of severity: AIS A. Intervention: Individuals performed 45min of wheelchair ergometry 3 times/wk for 6wk. Nine successive exercise bouts consisted of a 4min period of moderate exercise (base level) and a 1min period of intense exercise ($_{peak}$ level). The peak and base loads were ↑ by 10 W/2 min until the individuals were no longer able to maintain the required speed. Outcome Measures: Breath-by-breath gas analyser system, Telemetry.	production, and oxygen pulse (O_{2p}), ↑ significantly after wheelchair training ($p<0.05$). 2. HR_{peak} and respiratory rate were unchanged after training ($p>0.05$). 3. Changes in ventilation (V_E) $_{peak}$ and tidal volume (V_t) were not significantly different ($p>0.05$). 4. At the ventilatory threshold, there was a significant improvement in power output (W), VO_2, VCO_2, V_E, and O_2 after training ($p<0.01$). 5. During the same training session performed at the same loads before and after training, HR was significantly lower at the last base ($p<0.01$). There was a significant difference at the last peak in in O_{2p} and in V_E ($p<0.05$). 6. Base intensity and peak intensity were significantly lower after training in V_E ($p<0.05$). 7. Base intensity was significantly lower after training in VO_2 ($p<0.05$). 8. Total physical work (TPW) was improved between the first and last training session ($p<0.01$).
Yim et al. (1993) Korea Pre-post N=11	Population: Mean age: 30.9yr; Gender: males=11, females=0; level of lesion: T8-T12=11; Mean time post injury: 20.6mo. Intervention: Participants completed wheelchair ergometer	1. The mean HR_{peak}, the mean peak systolic blood pressure and the mean time required for 100m wheelchair propelling at resistance level 1 were significantly ↓ at the end of 5 weeks of training as

	training three times a week for five weeks. Each exercise session was 30min long, consisting of three, 10-minute exercise sets with 5 minutes rest in between. Participants were encouraged to maintain a velocity of more than 3 km/h at each resistance. Participants were assessed before and after the full training period. Outcome Measures: Mean heart rate, mean peak systolic blood pressure, time for 100m wheelchair propelling.	compared with those at the pre-training ($p<0.05$). 2. There was no statistically significant difference in the mean resting heart rate, the mean resting systolic and diastolic blood pressure when running 100m at resistance level 1 of wheelchair ergometer at pre- and post-training. 3. There was no statistically significant difference in pulmonary function pre- and post-training. 4. The mean peak torque of shoulder flexor and the mean total work of the elbow flexor was shown with significant ↑ from pre to post exercise ($p<0.05$). There were no statistically significant differences in the mean peak torque and the mean total work for flexors and extensors of shoulder and elbow at the end of the training period.
Hooker & Wells (1989) USA Prospective Controlled Trial N=8	Population: Low-intensity group: n = 6, 3 male, 3 female, C5-T10, age 26–36yr, 3 months to 19yr post-injury; moderate-intensity group: n = 5, 3 male, 2 female, C5-T9, age 23–30yr, 2–19yr post-injury. Intervention: Wheelchair ergometry 20 min/d, 3 d/wk, 8wk: low-intensity (50%–60% peak HRR) and moderate intensity (70%–80% peak HRR). Outcome Measures: total cholesterol (TC), triglycerides, HDL, LDL.	1. No change in VO_{2peak} or PO_{peak}. 2. lipid levels in low-intensity group. Significant ↑ in HDL and ↓ in triglycerides, LDL, and the TC/HDL ratio in the moderate intensity group.

Tordi et al. (2001) France Pre Post N=5	Population: Mean age: 27yr; Gender: males=5, females=0; Level of injury: Th6-L4. Intervention: Paraplegic men performed 30-min wheelchair ergometry 3x/wk for 4wk. The training program based on the the Square Wave Endurance Exercise Test (SWEET) consisted of six successive workouts of 5 min each. During each workout, a 4-min period of moderate exercise, named "base" level, was followed by a 1-min period of intense exercise, named "peak" level. Maximal dynamic performance and endurance capacity were studied before and after the training program with an incremental test (10 W/2 min) until volitional fatigue and a constant work rate test, respectively. Cardiorespiratory responses were continuously studied during each of these tests. Outcome Measures: Ventilation, respiratory rate, tidal volume (VT), oxygen uptake ($V0_2$), VCO_2 and CO_2 production, Heart rate (HR).	1. Wheelchair training produced a significant ↑ in peak tolerated power, in VO_{2peak} VCO_2, O_2p (all $p<0.05$). Peak HR was significantly lower after the training. 2. Pre to post training participants were able to maintain the load applied during the constant test for a significantly longer period of time.
Gauthier et al. (2018) Canada RCT PEDro=5 $N_{Initial}=11$, $N_{Final}=9$	Population: HIIT Group (n=4): Mean age=33.9yr; Gender: males=3, females=1; Level of injury range: C7-T10; Mean time since injury: 6.0yr. MICT Group (n=5): Mean age=43.2yr; Gender: males=3, females=1; Level of injury range: C6-T11; Mean time since injury: 15.5yr. Intervention: Participants were randomized to a home-	1. There were no statistically significant within group differences from pre- to post intervention. There were also no statistically significant between group differences for the relative change (expressed as a percentage) in cardiorespiratory fitness. ($p>0.05$).

	based self-managed manual wheelchair program. Weelchair ergo! The high-intensity interval training (HIIT) group alternated 30s high-intensity intervals (6 – 8, Borg CR10 scale) and 60s low-intensity intervals (1 – 2, Borg CR10 scale). The moderate-intensity continuous training (MICT) maintained a constant moderate intensity (4 – 5, Borg CR10 scale). The programs were six wks, consisting of three 40-min wheelchair propulsion training session/wk. Outcome Measures: Cardiorespiratory Fitness: VO_{2peak}, Heart Rate (HR), PO_{peak}, RPEmuscu, RPEcardio; Upper Limb Strength: Shoulder (flexors, extensors, abductors, adductors, internal rotators, external rotators), Elbow (flexors, extensors). Shoulder pain measured via the WUSPI	2. Similarly, upper-limb strength did not significantly improve between groups for all outcome measures ($p>0.05$). 3. Special consideration should be given to shoulder pain when initiating a HIIT intervention, especially in those with prior shoulder pain. Besides this, a home-based manual wheelchair HIIT program appears feasible and safe.
van der Scheer et al. (2016) Netherlands RCT PEDro=7 N=29	Population: *Exercise Group* (n=14): Median age=55yr; Gender: males=12, females=2; Level of injury range: C4-L5; Median time since injury: 16.0yr. *Control Group* (n=15): Median age= 57yr; Gender: males=10, females=5; Level of injury range: C4-L5; Median time since injury: 20.0yr. Intervention: Inactive manual wheelchairs (MWC) users were randomized to an wheelchair propulstion exercise group or no exercise group. The low-intensity	1. Participants were, on average, able to ↑ power output and velocity over the training period. 2. 10/14 participants felt that the training improved their fitness. 3. Most participants reported that wheelchair skill performance and physical activity levels had not changed. 4. No significant training effects were found in peak

	training program (30–40% HRR or 1-3 RPE on a Borg CR10 scale) was 16wks, consisting of wheelchair treadmill propulsion 2x/wk for 30min. Outcome Measures: $_{peak}$ aerobic work capacity: VO_{2peak}, PO_{peak}; Submaximal fitness: MEsub1, MEsub2; Anaerobic work capacity: 5s $_{peak}$ power output over a 15-m overground sprint (P5-15m); Isometric Strength; Wheelchair Skills Performance (WSP): performance time, ability score, strain score; Physical activity levels: Physical Activity Scale for Individuals with Physical Disabilities (PASIPD), distance.	aerobic work capacity, WSP or Physical activity levels. 5. P5-15m was the only outcome measure that was statically significant between the control and intervention group (p=0.02).

Discussion

Eight studies were identified that examined the effect of wheelchair propulsion training on cardiorespiratory fitness and/or endurance. There is level 1b evidence from 1 RCT study showing that low intensity wheelchair propulsion for 2 sessions per week for 16 weeks fails to elicit an increase in cardiorespiratory fitness. Level 2 evidence from two studies (one RCT and one prospective control) shows that increasing exercise intensity, albeit over a shorter 6 to 8 wk training period, does not result in greater improvements in cardiorespiratory fitness compared to lower intensity wheelchair propulsion. Of five pre/post studies, providing weaker evidence, one showed 12 wk of wheelchair propulsion did not ↑ VO_{2peak} while three showed that 4 to 6 wk of wheelchair population can modestly ↑ VO_{2peak}. Results at various evidence levels show similar incongruent findings for the effect of wheelchair propulsion on endurance performance: Level 1b evidence from an RCT shows a benefit only on sprint performance (not endurance), while level 4 evidence from four pre/post studies show evidence of benefit on endurance. One pre/post study suggests potential for wheelchair propulsion training to benefit pulmonary function, while two other pre/post studies show no effect of this training.

Conclusion

Van der Scheer et al (van der Scheer et al. 2016) provides Level 1 evidence that 16 wk of 2 day/wk of wheelchair pushing benefits endurance performance but can do so without improving VO_{2peak}.

Hooker and Wells (Hooker & Wells 1989) provided Level 2 evidence that 8 wk of 3 day/wk of wheelchair pushing can have no effect of VO_{2peak} and PO_{peak} while benefitting some blood lipid measures.

Fauthier et al provides Level 2 evidence that 6 wk of 3 day/wk of wheelchair pushing can result in no effect on cardiorespiratory fitness or performance.

Keyser et al (Keyser et al. 2003) provided Level 4 evidence that 6 - 12 wk of wheelchair pushing benefits PO_{peak}.

Le Foll-de Moro et al (Le Foll-de Moro et al. 2005) provided Level 4 evidence that 6 wk of 3 day/wk of wheelchair pushing benefits VO_{2peak} and some measures of pulmonary function.

Bougenot et al (Bougenot et al. 2003) provided Level 4 evidence that 6 wk of 3 day/wk of wheelchair pushing benefits VO_{2peak}, endurance performance, and some measures of pulmonary function.

Tordi et al (Tordi et al. 2001) provided Level 4 evidence that 4 wk of 3day/wk of wheelchair pushing benefits VO_{2peak} and endurance performance

3.1.3 Neuromuscular Electrical Simulation (NMES) Training

Neuromuscular electrical stimulation (NMES), delivered transcutaneously via electrodes placed on the skin over the target muscles, can be used to evoke muscle contractions. Devices have been constructed so that NMES can be used as a form of exercise. One common approach is NMES leg cycling, often known as functional electrical stimulation (FES) cycling. For practical purposes, we will use the common nomenclature “FES” when describing certain NMES approaches (such as “FES leg cycling”, “FES rowing”, etc.) and the term “NMES” for others (such as “NMES resistance training”) despite the fact that all approaches use NMES technology. In this approach, a computer controls the phasic cycling activation of different leg muscle groups so that contractions are coordinated to power a leg cycle. Other approaches can be used, such as pairing NMES with resistance exercise movements (such as knee extension). It should be noted that some investigators have used low-intensity/high-volume NMES approach where the muscle is tonically activated with a low level of stimulation that is sustained for a prolonged period of time. This approach will not be covered in this chapter.

Table 3. Effect of Various Forms of Neuromuscular Electrical Stimulation Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Functional Electrical Stimulation Leg Cycling Exercise (FES-LCE)		
Gorgey et al. (2017) USA RCT PEDro=5 N=9	Population: 9 SCI participants. SCI: C8-T10, AIS A (*n=8)* AIS B (n=1), AIS C=0. *Arm Cycling Exercise (ACE) (n=5)*: age 41±13yr, Time since injury (TSI): 11±9yr. *FES-LEC (n=4):* age 37±7yr, TSI: 7±5yr. Intervention: 16 weeks FES-LCE or ACE, 5 sessions / week. *ACE:* 10 min warmup, followed by 40 min of training, 10 min cool-down. Workload adjusted to maintain a $_{peak}$ heart rate (HR) at 75% of HR_{peak}. *FES-LCE:* cycling on ERGYS 2 with bilateral stimulation of the quadriceps, hamstrings, and gluteal muscles. Muscles stimulated at 60 Hz with current amplitude (140 mA) necessary to complete 40 min cycling at 50 RPM, progressively greater resistance over training. Outcome Measures: Systolic and diastolic blood pressure, HR (rest and $_{peak}$)	1. Resting systolic and diastolic blood pressures did not change following either ACE or FES-LES training 2. No changes to resting HR or HR_{peak} following ACE or FES-LCE training
Berry et al. (2012) UK Longitudinal study N=11	Population: 11 SCI participants (2 female). Age 41.8±7.6 yrs. SCI: T3-T9, TSI ≥ 2 yrs, all AIS A. Intervention: 12 months, home-based progressive FES-LCE program. Up to 5,	1. No significant change to oxygen cost and efficiency. 2. Total stimulation cost and blood lactate values reduced overall.

	60-minute sessions / wk. Outcome Measures: Stimulation cost, oxygen cost, efficiency, and markers of anaerobic metabolism before and after 6 and 12 months of training, during constant work-rate tests.	
Berry et al. (2008) UK Pre-Post N=11	Population: 12 SCI participants (2 female). SCI: 73-T12, AIS A (motor and sensory complete) Intervention: 52 weeks (1 year) FES-LCE, 236 sessions. Outcome Measures: Heart rate, O_2 pulse, power output.	1. ↑ to HR_{peak} (13%) and $_{peak}$ O_2 pulse after 6 months. 2. Significant improvements to $_{peak}$ power output after 3 months and 6 months.
Zbogar et al. (2008) Canada Pre-Post N=4	Population: 4 SCI participants, all female. Age 19-51, lesion level C4-T7 Intervention: 12 weeks LES-LCE. 30-minute sessions, 3 session / week. Outcome Measures: Large and small artery compliance	1. No significant change in large artery compliance 2. ↑ small artery compliance after training ~63% ↑ (range 4.2 + 1.8 to 6.9 + 3.2 mL/mmHg-1 × 100).
Janssen & Pringle (2008) The Netherlands Pre-Post N=12	Population: 12 male SCI participants, 6 tetraplegia and 6 paraplegia; 4 experienced and 8 novice with FES-LCE. Age 36±16 yrs, SCI: C4-T11, TSI: 11±9 yrs. Intervention: 6 weeks “modified” FES-LCE involving modified muscle activation and ITP design. 2-3 sessions / wk (total 18 sessions). In each session participants accumulated 25-30 mins of exercise, intervals of 5-10 mins exercise with 5 min rest. Applied progressive overload of duration and resistance. Outcome Measures: Heart rate; power output; oxygen uptake (VO_{2peak}); minute	1. ↑ HR_{peak} (+16%) and power output (+57%) after training 2. ↑ VO_{2peak} (+29%) and VE_{peak} (+19%). 3. No change to stroke volume of cardiac output 4. No significant differences with training when looking solely at tetra, para, experienced or novice separately

	ventilation (VE); stroke volume and cardiac output via impedance cardiography	
Hopman et al. (2002) The Netherlands Pre-Post N=9	Population: 9 males with SCI. Age 40.7±7.2 yrs. SCI: T4-T12, AIS-A, TSI 12.8±7.6 yrs (range 1-22 yrs). **note data from 3 participants omitted due to their medications, final n=6** Intervention: 6 weeks FES-LCE training with electrodes placed over hamstring, gluteal, and quadriceps muscles. 30 mins per session, 3 session / wk Outcome Measures: Mean arterial pressure (MAP), resting femoral artery (FA) blood flow	1. "↑" in workload from 4±5 kJ to 16±14 kJ (no statistics provided) during training 2. No change in MAP 3. ↑ resting femoral artery blood flow: Peak systolic blood flow 1330 ± 550 to 1710 ± 490 mL/min, mean blood flow from 270 ± 120 to 370 ± 160 mL/min. 4. Calculated vascular resistance ↓ by 30% after 6 weeks of training (no statistics).
Gerrits et al. (2001) The Netherlands Pre-Post N=9	Population: 9 males with SCI. Age mean 39.2 yrs, range 26-61. SCI: C4-T8, 4 cervical and 5 thoracic; 5 AIS-A, 3 AIS-B, 1 AIS-C;TSI: mean 11.1 yrs, range 2-27. Intervention: 6 weeks FES-LCE ergometry (LCE), 3 sessions / wk. Sessions were 30 minutes exercise with electrodes on hamstrings, glutes and quadriceps, target 50 RPM. Outcome Measures: Common carotid artery (CA) and femoral artery (FA) diameters, inflow volumes (peak systolic, PSIV; mean, MIV) and velocity index (VI; representing peripheral resistance) via longitudinal imaging and Doppler velocity spectra	1. Average work output over the first 3 sessions vs last 3 ↑ (4 ±5 kJ to 16±14 kJ, p<0.01) 2. No change HR and systolic BP 3. ↑ FA diameter (pre-training 7.5±1.5 mm vs. post-raining 8.1±1.5 mm), no change CA diameter. 4. FA VI ↓ from 1.24±0.11 to 1.14±0.12 (p<0.01) but VI was unchanged in CA 5. Significant ↑ to resting inflow volumes in the FA (PSIV 1330 ± 550 to 1710 ± 490 mL/min and MIV 270 ± 120 to 370 ± 160 mL/min), ↑ in CA not significant 6. ↑ hyperaemic response to occlusion post-training.

Hjeltnes et al. (1997) Norway Pre-Post N=5	Population: 5 males with SCI. Age 35±3 yrs. SCI: C5-C7 AIS-A except one AIS-A/B, TSI: 10.2±3.4 yrs. Intervention: 8 weeks FES-LCE “full” training phase preceded by 2 weeks “run-in” period for adaptation. Full training was 7 sessions / week (once per day for 3 days, twice per day for 2 days). Outcome Measures: $_{peak}$ oxygen uptake (VO_{2peak}) and workload, pulmonary function (vital capacity, VC; forced expiratory volume (FEV); total lung capacity (TLC); lung diffusion capacity (DLCO).	1. VO_{2peak} ↑ (70%) during FES-LCE but unchanged during ACE. 2. VO_{2peak} during FES-LCE became similar to peak values during ACE post-training 3. No changes to pulmonary measures (VC, FEV, DLCO, TLC or RV) after training
Barstow et al. (1996) USA Pre-Post N=9	Population: 9 males with SCI. Age 34.4 ± 5.6 yrs. SCI: 2 tetraplegia, 7 paraplegia, all AIS-A,TSI: 10.1 ± 4.1 yrs. Intervention: FES-LCE, minimum 24 sessions, 30 mins per session, minimum of 24 sessions. Sessions averaged 2.1±0.4/week. Increasing work rate as tolerated. Outcome Measures: Work rate, VO_{2peak}, oxygen pulse measured during incremental and constant work rate tests on cycle ergometer	1. Training significantly ↑ VO_{2peak} (10.9%), peak work rate (46.5%), and $_{peak}$ oxygen pulse (12.6%). 2. No change in HR_{peak} 3. Improved (faster) VO_2 and VE kinetics post-training
Faghri et al. (1992) USA Pre-Post N=13	Population: 13 participants with SCI (3 female). Age 30.5 ±5 yrs. SCI: 6 paraplegia (5 complete, AIS A-B, T5-T10), 7 tetraplegia (all AIS-B to D, C4-T5), TSI 8 ± 4 yrs. Intervention: 12 weeks FES-LCE, total 36 sessions. All started at 0W in first three	1. Both para and quad improved continuous exercising PO (no stats), similar improvements between groups 2. No change in VO_2, a-VO_2 diff, RER or VE responses to submaximal exercise

	sessions, load ↑ when possible. Outcome Measures: Stroke volume (SV) and cardiac output (Q) assessed with impedance cardiography; blood pressure (SBP, DBP, MAP), HR; VO_{2peak} and $_{peak}$ PO; ventilation (VE), arterio-venous difference of oxygen (a-VO_2), and respiratory exchange ratio (RER). Assessed at rest and during 5 mins FES-LCE at 0W "submaximal" work.	3. ↑ HR and SBP in quad; ↓ BP, DBP and MAP in para 4. Across all participants, during submax exercise ↓ HR and BP but ↑ SV and Q (↑ Q was most notable in the para group)
Hooker et al. (1992) USA Pre-Post N=18	Population: 18 participants with SCI (1 female). Age: 30.6 ± 0.45 yrs (SE). SCI: 10 quadriplegia (C5-C7; 2 complete), 8 paraplegia (T4-T11; 6 complete), TSI: 6.1 ± 0.25 yrs (SE). Intervention: FES-LCE. Total of 36 sessions completed over 13.6 ± 0.9 weeks (~2.7 sessions per week), 10-30 minutes per session. Outcome Measures: VO_{2peak}, power output (PO), and ventilation (VE) assessed with metabolic cart. Estimations of cardiac output (Q) and stroke volume (SV) with impedance cardiography. Blood pressure, total peripheral resistance (TPR) and HR also reported.	1. ↑ PO_{peak} and VO_{2peak}, and $_{peak}$ VE and HR responses to $_{peak}$ FES-LCE, no change during ACE test. 2. ↑ peak Q response due to ↑ HR_{peak}, and reduced TPR response during FES-LCE 3. No change in responses of SV, MAP or a-VO_2 difference during FES-LCE or ACE 4. No changes pre-post training in any measures during ACE testing.
Hooker et al. (1995) USA Pre-Post Test N=8	Population: 8 males with SCI. Age 36 ± 5.4yr. SCI: two C5-C7, six T4-L1, all Frankel Class A, TSI: 9.8 ± 4.0 yrs. Intervention: 19 weeks FES-LCE (called "NMES leg cycling"), minimum 24 (38 ± 17) 30-minute sessions.	1. For the graded cycle ergometer test to fatigue, there was a significant ↑ in VO_2 after training ($p=0.04$), but when calculated per kilogram of body weight, this difference was no longer significant ($p=0.07$). All other outcomes did not

	NMES was applied to the quadriceps, gluteal and hamstring muscles. *Phase I*: duration started at 10-15min and progressively ↑ until they could perform 30 minutes of continuous cycling. 2 session per week, 7 weeks. *Phase II:* resistance on the cycle was progressively ↑. Outcome Measures: Work rate, VO_2, heart rate, pulmonary ventilation and respiratory exchange rate.	significantly change after training. 2. During steady rate cycle test, ↓ respiratory exchange rate after training ($p<0.05$), but no other significant changes
Ragnarsson (1988) USA Pre-Post N=19 Study I, N=11 Study II	Population: *Study I:* 19 participants with SCI (3 female). Age 19-47 yrs. SCI: paraplegia=7, quadriplegia=12, TSI 2-17 yrs. *Study II:* 11 participants with SCI (4 female). Age 18-54 yrs. SCI: paraplegia=4, quadriplegia=7, TSI 7months - 11yrs. Intervention (same for both Study I and II). Phase I: quadriceps stimulation with dynamic knee extensions against increasing resistance, 3 sessions / week for 4 weeks. Phase II: 12 weeks FES-LCE, 15-30 minutes / session, 3 sessions / week Outcome Measures: VO_{2peak}, $_{peak}$ work rate, heart rate and blood pressure	1. Most showed an ↑ in strength and endurance. 2. During arm-crank ergometer stress tests VO_{2peak} ↑ non-significantly (14.9%) after training
Pollack et al. (1989) USA Pre-Post N=11d	Population: 11 participants with SCI (4 female), age 18-54 yrs. SCI: C4-C6 and T2-T6, motor-complete, TSI: 6–132 months. Intervention: 3 phase program over 13–28wk. Phase I: quadriceps	1. No change in any resting measures 2. ↑ endurance time (288%), VO_{2peak} (95.9%), and $_{peak}$ HR (16.8%) 3. ↓ diastolic BP response (31.5%) with training, no

	stimulation (knee extension); Phase II: FES leg cycle with 0–1 kp resistance; Phase III: loaded FES leg cycle, 3 d/wk, 3 wk. Outcome Measures: VO_{2peak}, endurance time, heart rate (HR), blood pressure (BP), ventilation (VE) and tidal volume (VT)	change systolic BP response 4. ↑ VE_{peak}, but no significant changes to VT_{peak} or breathing frequency
Functional Electrical Stimulation Ambulation – PARASTEP® 1		
Nash et al. (1997) USA Pre-Post N=12	Population: 12 participants with SCI (1 female). Age 28 ± 7.2 yrs. SCI: T4-T11, TSI: 3.9 ± 3.1 yrs. Intervention: 12 weeks PARASTEP ambulation training (FES of lower extremities with rolling walker), total 32 sessions. Outcome Measures: Common femoral artery (CFA) diameter and flow velocity profiles assessed with Doppler ultrasound at rest and after 5 min thigh occlusion: flow-velocity integral (FVI), cross sectional area (CSA), inflow volume (IV), pulse volume (PV= CSA*FVI), $_{peak}$ systolic velocity (PSV), arterial inflow volume (AIV)	1. Significant effects of training for resting CSA, HR, FVI, PV and AIV; no change in PSV 2. 33% ↑ in FA CSA ($p<0.001$) and ↓ HR by 7 bpm ($p<0.05$) 3. ↑ resting FVI and PV by 26% and 67% respectively ($p<0.05$, $p=0.001$) 1. ↑ resting AIV 417 to 650 ml/min ($p<0.01$) 2. AIV response 1 minute post-occlusion ↑ 78.2% in absolute magnitude and 17.4% when expressed as % change from baseline. After 1 min though no differences pre- vs post-training
Jacobs et al. (1997) USA Pre-Post N=15	Population: 15 participants with SCI (3 female). Age: 28.2 ± 6.8 yrs, range 21.1-45.2 yrs. SCI: T4-T11, all paraplegia AIS-A, TSI 3.7 ± 3.0 yrs range 7-8.8 yrs. Intervention: 32 sessions of Parastep ® 1 functional neuromuscular stimulation ambulation training. 3 sessions / week. Typically, three walking trials were	1. Lowered HR throughout sub-$_{peak}$ levels of arm ergometry post-training 2. ↑ VO_{2peak} from 20.0 ± 3.3 mL/kg/min to 23.0 ±3.6 mL/kg/min post-training

	completed during each training session. Participants chose ambulation pace and duration. Outcome Measures: heart rate (HR), $_{peak}$ VO_2.	
FES Hybrid Leg-Cycling Ergometry with Voluntary Arm Crank (FES-LCE+ACE)		
Bakkum et al. (2015) Netherlands RCT PEDro=6 N=19	Population: 19 participants with SCI (1 female). SCI: C2-L2, TSI: >10 years. Intervention: 16 weeks, participants randomized to FES-LCE+ACE (n=9) or ACE alone (n=10). 32 sessions, 18-32 minutes per session (↑ across program). Interval training protocol. Outcome Measures: Systolic and diastolic blood pressure are only cardiorespiratory measures, all others are metabolic.	1. Lowered diastolic blood pressure
Brurok et al. (2011) Norway Pre-Post N=6	Population: 6 men with SCI in stable neurologic recovery (5 participants – paraplegic AIS A, 1 participant – tetraplegic AIS A). Intervention: 8 weeks FES-LCE+ACE, aerobic high-intensity hybrid exercise training, 3 session per week. Training preceded by a 7 week control period of regular daily activity. Peak tests were performed at three different time points: 1, baseline; 2, control; and 3, post-training. Outcome Measures: Peak stroke volume (SV) during hybrid cycling and VO_{2peak} during FES-LCE+ACE, arm	1. Between the control and post training test, ↑ in VO_{2peak} (25.3%) during FES-LCE+ARM, and VO_{2peak} during ACE (25.9%) and FES-LCE (25.8%).

	cycle ergometry (ACE), and FES-LCE	
Gurney et al. (1998) USA Pre-Post N=6	Population: 6 males with SCI. Ages 23-41 yrs. SCI: C4-T10, 4 paraplegia, 2 tetraplegia, TSI 5–24 yrs. Intervention: Phase I: FES-LCE, 3 sessions / week for 6 weeks. Phase II: FES-LCE+ACE, 3 session / week for 6 weeks. Phase III: 8 weeks detraining. Outcome Measures: VO_{2peak}, submaximal and maximal HR.	1. ↑ VO_{2peak} (81.7%) and workload with FES-LCE+ARM. 2. After detraining period, PO_{peak} returned to baseline; VO_{2peak} remained higher.
Mutton et al. (1997) USA Pre-Post N=11	Population: 11 males with SCI. Mean age 35.6 yrs. SCI: C5-6 to T12-L1, all AIS A, TSI mean 9.7 yrs. Intervention: Phase I: progressive FES-LCE to 30min of exercise; Phase II: ~35 sessions of FES-LCE; Phase III: ~41 sessions, 30 mins each of combined FES-LCE+ACE. Outcome Measures: VO_{2peak} and submaximal physiological parameters (VO_2, HR, blood lactate).	1. ↑ VO_{2peak} (13%) and PO_{peak} (28%) during graded hybrid testing, but not during graded ACE or graded FES-LCE testing alone.
Krauss et al. (1993) USA Pre-Post N=8	Population: 8 participants with SCI (1 female). Age 32 ± 2 yrs. SCI: 7 paraplegia, 1 tetraplegia, TPI: 13 ± 2 yrs. Intervention: Phase I: FES-LCE, 6 weeks, 3 sessions / week. Phase II: FES-LCE+ACE for 6 weeks. Outcome Measures: VO_{2peak}, HR, workload, peak lactate.	1. After Phase I, ↑ VO_{2peak} during ACE (21.9%) and FES-LCE (62.7%). 2. After Phase II, ↑VO_{2peak} during FES-LCE+ACE by 13.7%. 3. HR_{peak} only ↑ with training during FES-LCE.
FES Rowing (FES-ROW)		

Wheeler et al. (2002) Canada Pre-Post N=6	Population: 6 with SCI (sex not defined, likely all male): 5 paraplegia (AIS-A, T4-12) and 1 quadriplegia (AIS-C, C7), TSI 13.8 ± 11.6 yrs. Age 42.5 ± 17.9 yrs Intervention: 12 weeks FES-ROW (quadriceps) at 70%–75%VO_{2peak}, 30 mins per session, 3 sessions / week. Outcome Measures: VO_{2peak}, ${}_{peak}$ O2 pulse and total rowing distance during arm-only rowing, FES bilateral lower-extremity flexion and extension (LFES) and hybrid exercise (FES-ROW).	1. Post-training during FES-ROW: ↑ rowing distance (25%, $p<0.02$), VO_{2peak} (11.2%, $p<0.001$), and peak oxygen pulse (11.4%, $p<0.01$). 2. HR_{peak} response to hybrid training was unchanged, but HR_{peak} with LFES ↑ ($p<0.01$)
Solinsky et al. (2020) USA Pre-Post N=40	Population: 40 participants with SCI (6 female). Age 34.1 ± 12.4cyrs. SCI: C1-T1=21, T2-L5=18 Unknown=1; AIS A=19, AIS B=8, AIS C=5, AIS D=2, AIS Unknown=6; TSI 41.4 ± 87.4 months. Intervention: 6 months FES-ROW. Goal of 2-3 sessions / week at a goal > 75% HR_{max}. Individuals averaged 42.1 ± 22.0 min of FES rowing per week, 1.69 sessions per week. Outcome Measures: VO_{2peak}, Cardiometabolic Disease (CMD) indicators	1. ↑ $VO2_{peak}$ $p<0.001$
Jeon et al. (2010) Canada Pre-Post N=6	Population: 6 male participants with paraplegia. SCI: T4-T5 and T10, age 48.6 ± 6.0 y. Intervention: 12 weeks of FES-ROW 3-4 sessions per week (600–800 kcal per week). Outcome Measures: VO_{2peak} (plus metabolic markers)	1. ↑ VO_{2peak} from 21.4 ± 1.2 to 23.1 ± 0.8 mL/kg/min ($P = 0.048$)

Gibbons et al. (2016) UK Observational and Pre-Post N=14	Population: Study-1: *FES-untrained (FES-UT) males (n=3):* Age 38 ± 14 yrs; C4=1, T6-8=2; AIS A. *FES-untrained (FES-UT) females (n=3)*: Age 33 ± 1 yrs; C6-7=2, T10=1; AIS A=2, AIS B=1. *FES-trained (FES-T; n=3):* Age 42 ± 15 yrs (males); C6=1, T2-T4=2; AIS A. Study-2: *FES-naïve* (n=5, 4 females): C4-6=3, T6-10=2; AIS A. Intervention: Study-1. Cross-sectional study. Resting cardiac ultrasound assessment then incremental arm crank exercise (ACE) test. Study-2. Progressive structured FES-ROW training with two conditioning phases to ↑ quadriceps fatigue resistance and force-generating characteristics and a third intervention phase for 8 weeks. Outcome Measures: cardiac ultrasound, VO_{2peak}, work rate	Study-1: 1. VO_{2peak} during ACE was not different between FES-UT and FES-T. 2. Left ventricular internal diameter diastole (LVIDd), end-diastolic volume (EDV), relative EDV (REDV), end-systolic volume (ESV), and relative ESV (RESV) were lower in FES-UT females, and LVIDd was lower in FES-UT males, compared to FES-T 3. Relative wall thickness diastole (RWTd) was higher in FES-UT vs FES-T 4. Early to late diastole ratio (E/A), early septal myocardial tissue velocity diastole (E') and early to late septal tissue velocity diastole ratio (E'/A') was lower and early LV relaxation diastole to early septal myocardial tissue velocity diastole ratio (E/E') was higher in FES-UT compared with FES-T 5. Stroke volume (SV) and cardiac output (Q) were lower and resting HR was higher in FES-UT compared to FES-T 6. No differences in blood pressure between groups Study-2: 1. Individual ACE VO_{2peak} and PO_{peak} ↑ with training, and FES-ROW VO_{2peak} and PO_{peak} ↑ during Phase-3 2. ↑ LVIDd, EDV, REDV, ESV and left ventricular mass training and ↓ RWTd 3. ↑ Early LV relaxation diastole (E), E/A, E', E'/A' and

		flow propagation velocity (FPV) ↑ with training ↓ LV relaxation diastole (A), late diastole tissue velocity (A') and E/E' 4. SV, ejection fraction (EF) and Q ↑ with training
Qiu et al. (2016) USA Pre-Post N=12	Population: 12 participants with SCI (1 female). Age 33.3 ± 3.8 yrs. SCI: T2-C4=12; TPI 8.3 ± 3.3 yrs Intervention: FES-ROW. Training 3 times / week and only advanced to FES-RT when 30 min of full knee extension was achieved. All participants underwent the FES-RT 3 sessions / week for 6 months, goal of reaching an exercise intensity of 75-85% of HR_{peak} for 30 continuous minutes. Outcome Measures: aerobic capacity (VO_{2peak}), peak ventilation (V_{Epeak}), peak tidal volume (V_{Tpeak}), peak breathing frequency (BF_{peak}), peak espiratory exchange ratio (RER_{peak}), peak heart rate (HR_{peak}), oxygen uptake efficiency slope (OUES).	1. ↑ VO_{2peak} on average by 12% with 6 months of FES-RT, from 15.3 ± 1.5 to 17.1 ± 1.6 $mL/kg^{-1}/min^{-1}$ (p=0.02), and 28% ↑ in $_{peak}$ wattage (34.6 ± 4.4 versus 44.4 ± 5.7 W, p<0.01). 2. Average VE_{peak} did tend to be higher after FES-RT (37.5+ 4.4 versus 40.7 + 3.0 L/min^{-1}, p=0.09), but an ↑ was demonstrated in only 7 individuals. 3. No change RER_{peak} and HR_{peak}. 4. Average OUES was higher after 6 months of FES-RT (1.24 ± 0.11 versus 1.38 ± 0.12, p<0.05).
Kim et al. (2014) Korea Pre-Post N=12	Population: 12 participants with SCI (2 female). Age 36 ± 12 yr. SCI: L1-C6; AIS A=7, B=1, C=4; TSI 11.4 ± 5.8 yr. Intervention: 6 weeks FES-ROW, 42.5 minutes / session, 5 session / week. 5 min warm-up, 32.5 min exercise (6 bouts of 5 minutes exercise 30s rest), and 5 min cool-down. During exercise aimed to maintain HR >70% of $_{peak}$ HR. Outcome measures were assessed at baseline and 6wk.	1. No significant change in $_{peak}$ oxygen consumption.

	Outcome Measures: Peak oxygen consumption during ACE test	
Taylor et al. (2014) United States Pre-Post N=14	Population: 14 SCI individuals (1 female). Age 39.2 ± 3.3 yrs. SCI: T3-T11, AIS-A, TSI 9.7 ± 2.6 years Intervention: First, variable period of FES 'strength training' (3-5 days per week until repetitive knee extension could be achieved for 30 mins). Then FES-ROW 3 days per week, consisting of multiple intervals of FES rowing interspersed with intervals of 3-5 mins arms-only rowing for total of 30 mins per session). Once they could complete 10 mins continuously of rowing, did lab-based RT 3 days per week for 6 months. Outcome Measures: Peak minute ventilation, peak aerobic capacity. Note that initial $_{peak}$ graded exercise tests were performed when muscle strength and endurance allowed for continuous FES-ROW >10 mins (range 2-6 weeks). Outcome tests were graded FES-ROW	1. ↑ VO_{2peak} (19.6±6.0 ml/kg/min to 21.4±6.6, p=0.02), VE_{peak} (54.1±13.5 L/min to 60.3±13.5 L/min, p=0.01), 2. No change HR_{peak} or power output (p=0.07) 3. Pre-training, significant correlation between LOI and VO_{2peak} (adj r^2=0.50, p<0.01), and LOI and VE_{peak} (adj r^2=0.38, p=0.01) 4. Post-training, relationship between VO_{2peak} and LOI was non-significant, while correlation between VE_{peak} and LOI remained (adj r^2=0.58, p=0.001)
Vivodtzev et al (2020) USA RCT PEDro=3 N=9	Population: *NIV:* Mean age: 42.8yr; Level of injury: C1-T1=5, T2-T3=1; Level of severity: AIS A=3, AIS C=3; Mean time since injury: 13.7yr. *Sham:* Mean age: 31yr; Level of injury: C1-T1=2, T2-T3=1; Level of severity: AIS A=1, AIS B=1, AIS C=1; Mean time since injury: 11.3yr. Intervention: Ventilatory support during whole-body	1. Training with NIV ↑ OUES compared to baseline (4.1 ± 1.1 versus. 3.4 ± 1.0, i.e., +20 ± 12%, p<0.05) and sham (p=0.01), thus illustrating an ↑ in the ability to uptake oxygen. 2. ↑ OUES result also seen when no NIV during test, this suggests improved cardiopulmonary reserve

	FES rowing. All participants had training adaptations plateauing for more than 6 months before enrolling the study. After baseline assessment participants continued training with randomly assigned non-invasive ventilation (NIV: n=6) or sham (n=3) for 3mo. Outcome Measures: oxygen uptake efficiency slope (OUES)	
Vivodtzev etl al (2020) USA RCT PEDro=7 N=19	Population: Mean age: 39.13yr; Level of injury: C4-T8=19; Level of severity: AIS A=8.5, AIS B=3.5, AIS C=7; Mean time since injury: 12.2yr. Intervention: Acute ventilatory support in the form of non-invasive ventilation (NIV) during whole-body rowing. All patients were familiar with functional electrical stimulation (FES) rowing and had plateaued in their training-related ↑ in aerobic capacities. Patients performed two FES-rowing $_{peak}$ exercise tests with NIV or without. Outcome Measures: oxygen uptake efficiency slope (OUES).	1. NIV ↑ the exercise tidal volume ($_{peak}$, 1.50±0.31 L versus 1.36±0.34 L; $p<0.05$) and reduced breathing frequency ($_{peak}$, 35±7 beats/min versus 38±6 beats/min; $p<0.05$) compared with the sham test, leading to no change in alveolar ventilation but a trend toward ↑ oxygen uptake efficiency ($p=0.06$). 2. In those who reached $_{peak}$ oxygen consumption (VO_{2peak}) criteria (n=13), NIV failed to significantly ↑ VO_{2peak} (1.73±0.66 L/min versus 1.78±0.59 L/min); however, the range of responses revealed a correlation between changes in $_{peak}$ alveolar ventilation and VO_{2peak} ($r=0.89$; $p<0.05$). Those with higher level injuries and shorter time since injury exhibited the greatest ↑ in VO_{2peak}.
Neuromuscular Electrical Stimulation Resistance Training (NMES-RT)		

Carty et al. (2012) Ireland Prospective cohort N=14	Population: Participants with T2-T11 SCI (3 female); 11 AIS A, 3 AIS B; age 45.08 ± 7.92; TSI 11.22 ±11.23 yrs. Intervention: 8 weeks NMES, 1 hour 5 times / week. Four electrodes were placed bilaterally on the quadriceps and hamstrings muscle groups, and subtetanic contractions were elicited using a neuromuscular electrical stimulation device. Participants ↑ the stimulation intensity on an incremental wheelchair exercise test of increasing speed and incline as quickly as tolerable to bring them to the desired training intensity as recorded on the Borg scale of rating of perceived exertion (RPE) (between 13 and 15 on RPE). Outcome Measures: Incremental treadmill wheelchair propulsion exercise test with simultaneous cardiopulmonary gas exchange analysis to determine VO_{2peak} and HR_{peak}.	1. ↑ VO_{2peak} and HR_{peak} between baseline and follow-up was observed. Changes in VO_{2peak} ranged from -1.1% to 57.2%. 2. No difference in the mean VO_{2peak} change between the 2 groups based on the level of injury (above T6, T6 and below).
Stoner et al. (2007) USA Pre-Post N=5	Population: 5 males with SCI. Age 35.6 ± 4.9 yrs. SCI: C5-T10, AIS A, TSI 13.4 ± 6.5 yr. Intervention: 18 weeks NMES, 2 session / week. Quadriceps femoris muscle group of both legs were trained with 4x10 repetitions of unilateral, dynamic knee extensions Outcomes Measures: FMD and resting diameter and arterial range of the	1. FMD improved from 0.08 ± 0.11 (2.7%) to 0.18 ± 0.15 (6.6%) and arterial range improved from 0.36 ± 0.28 mm to 0.94 ± 0.40 mm. Resting diameter did not change.

	posterior tibial artery.	
Sabatier et al. (2006) USA Pre-Post N=5	Population: 5 males with SCI. Age 35.6 ± 4.9 yrs, AIS A, TSI 13.4 ± 6.5 yrs Intervention: 18 weeks home-based NMES, twice per week. Outcome Measures: Femoral artery diameter and blood flow, weight lifted, muscle mass, and muscle fatigue.	1. ↑ weight lifted and muscle mass and a ↓ in muscle fatigue. 2. There was no change in femoral artery diameter with training. 3. Resting, reactive hyperaemia, and exercise blood flow did not change significantly with training.

Discussion

Fourteen studies have used FES leg cycling exercise (FES-LCE) as a training intervention with cardiorespiratory outcomes, ranging in duration from 6 weeks to 52 weeks. A single RCT study by Gorgey et al. (2017) compared the efficacy of 16 weeks FES-LCE versus arm-cycle ergometry (ACE) training. These authors reported that peak oxygen uptake was not significantly changed in either of the intervention groups, nor were resting heart rate or blood pressure. By contrast, of the single-cohort longitudinal studies, most reported concurrent improvements to both VO_{2peak} and PO_{peak} (or endurance time) during or following FES-LEC training. Of those that examined ventilatory parameters, only two out of six noted increased peak ventilation during graded stress tests (Janssen & Pringle 2008; Pollack et al. 1989), and Hjeltnes et al. (1997) did not observe any changes to resting lung volumes after training. Seven of the FES-LEC studies assessed blood pressure or arterial parameters. While resting blood pressure seems largely unchanged with training (four studies including an RCT), both Pollack (1989) and Faghri (1992) observed lower blood pressure responses to exercise, indicating positive cardiovascular adaptations with FES-LEC training. This is further supported by findings from Hopman et al. (2002) and Zbogar et al. (2008) indicating favourable vascular adaptations. Furthermore, most studies reporting on heart rate (HR) data found increased peak or submaximal exercising HR, though the RCT from Gorgey et al. (2017) did not see significant changes to HR_{peak}.

Of twelve studies involving hybrid FES training, five used hybrid FES that combines FES-LEC with voluntary arm cycling exercise (FES-LEC+ACE) and seven involved FES-rowing training. There was a single RCT by Bakkum et al. (2015) which compared FES-LCE+ACE versus ACE, though this study did not include cardiorespiratory data related to oxygen uptake or exercise performance, and otherwise only saw some reductions to resting diastolic blood pressure following the 16-week intervention. All studies but one reported improvements to VO_{2peak} in the ranges of ~10-100%, not only in FES-hybrid modalities but in some cases translating to other modalities like ACE alone and/or FES-LCE alone (Brurok et al. 2011; Gibbons et al. 2016; Krauss et al. 1993). Most often the improvements in oxygen uptake were accompanied by greater PO_{peak} during graded stress tests. The only study that didn't see improved VO_{2peak} was Kim et al. (2014) whose training duration was a relatively short 6 weeks and did otherwise report improved muscular strength. In contrast to findings from the FES-LCE studies, all hybrid FES studies reporting on ventilation found increases in peak ventilation responses during graded stress tests. Two studies assessing cardiac structure and function also noted increased cardiac output. Of note, Gibbons et al. (2016) performed detailed echocardiographic assessments in participants following FES-ROW training, and observed augmented heart mass, dimensions and improved ejection and filling function. Finally, two of the studies noted increased to peak HR during FES stress tests, while HR_{peak} was unchanged in three others.

Two studies using FES ambulation training, both with the commercial Parastep® system, found that training promoted favourable adaptations to the vascular system (i.e. larger arteries and greater flow responses) or improvements to VO_{2peak} following the training program. A single prospective cohort study by Carty et al. (2012) assessed the efficacy of 8 weeks of NMES resistance training, and found that participants improved VO_{2peak} in an incremental wheelchair test following their training. They also found increased peak HR across their full cohort. Only two other studies using NMES have reported cardiorespiratory data: Stoner et al. (2007) and Sabatier et al. (2006) have assessed arterial structure and function, but did not observe any changes to femoral artery diameter or resting function. Stoner (2007) did note improved blood flow responses post-occlusion, but these were not significant in Sabatier's (2006) participants.

Conclusions

There is Level 2 evidence (Carty et al. 2012) that 8 weeks of 1-hour NMES training, 5 times per week can improve aerobic capacity (ie. peak oxygen uptake), and allow individuals to achieve higher peak exercising HR.

There is level 4 evidence (Berry et al. 2008; Faghri et al. 1992; Gerrits et al. 2001; Hjeltnes et al. 1997; Hooker et al. 1992; Hooker et al. 1995; Hopman et al. 2002; Janssen & Pringle, 2008; Mutton et al. 1997; Pollack et al. 1989) that 6-52 weeks training with 2-3 sessios per week of FES training promotes improvements to aerobic capacity (ie. peak oxygen uptake) and exercise performance

There is Level 4 evidence (Janssen & Pringle 2008; Pollack et al. 1989) that 6-28 weeks, 2-3 sessions per week FES training can result in increased ventilatory capacity without not changes in lung volumes, per se.

There is Level 4 evidence (Hopman et al. 2002; Zbogar et al. 2008) that 6-12 weeks, 3 sessions per week FES training can lead to positive cardiovascular adaptations, including favourable alterations to arterial structure and function.

There is Level 4 evidence (Brurok et al. 2011; Gibbons et al. 2016; Gurney et al. 1998; Jeon et al. 2010; Krauss et al. 1993; Mutton et al. 1997; Qiu et al. 2016; Solinsky et al. 2020; Taylor et al. 2014; Wheeler et al. 2002) that 6-36 weeks FES-hybrid training (FES-LES+ACE and FES-rowing), results in improved aerobic capacity (ie. peak oxygen uptake) and exercise performance.

There is Level 4 evidence (Brurok et al. 2011; Mutton et al. 1997; Pollack et al. 1989; Qiu et al. 2016; Taylor et al. 2014) that 8-36 weeks FES-hybrid training can improve peak ventilation during exercise.

There is Level 4 evidence (Brurok et al. 2011; Gibbons et al. 2016) that FES-hybrid training (FES-LES+ACE and FES-rowing) can promote in positive cardiovascular adaptations, including increased heart size and improved pumping and filling function. This training may also increase peak exercising HR.

There is Level 4 evidence (Stoner et al. 2007) that 18 weeks NMES training, 2 times per week, may promote cardiovascular adaptations, including positive alterations to arterial structure and function.

3.1.4 Body-Weight Supported Treadmill Training (BWSTT)

Body-weight supported treadmill training (BWSTT) is an exercise protocol that involves supporting an individual over the top a motorized treadmill with a counterbalanced harness system. The premise of all BWSTT protocols is to offset some of an individual’s body weight to reduce the work associated with upright walking, using a weight stack to adjust the magnitude of support and treadmill speed to adjust the intensity of exercise. The degree of support as well as the amount of progression across a training period is highly individualized, determined by a trained therapist observing proper gait and cardiovascular responses. While BWSTT has garnered attention in functional movement rehabilitation, previous studies have indicated this strategy can also target conventional outcomes of cardiorespiratory fitness through a lower-intensity aerobic challenge. While the resources for this modality are high (i.e., specialized treadmill, lead therapist, volunteers to assist with leg movements), there is potential for BWSTT to target multiple exercise domains including upright posture challenges, cardiovascular effort, and lower-limb skeletal muscle involvement.

Table 4. Effect of Body-Weight Supported Treadmill Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Alexeeva et al. (2011) USA RCT PEDro=7 N=35	Population: SCI Group: Sex: males=30, females=5; Age (range): 16–70 yr; injury at or rostral to T10; able to rise to standing position with moderate assistance or less, and independently advance at least one leg. Intervention: Patients were randomized to 3 groups (body-weight-supported (BWS) walking on a fixed track vs. BWS walking on a treadmill vs. comprehensive physical therapy). The BWS groups used 30% BWS. Patients participated in a 13wk (1 hr/day, 3 d/wk) program. Outcome Measures: performance values, heart rate (HR), pre- and post-training 10-m walking speed, balance, muscle strength, fitness (VO_{2peak}), and quality of life.	1. Participants in the 'BWS walking on a fixed track' group achieved the highest average heart rate during training, whereas those in physical therapy had the lowest average heart rate. 2. In all three groups there was a clinically important post-training ↑ in average normalized VO_{2peak} (~12% in each group); however, these differences did not achieve statistical significance.
Millar et al. (2009) Canada RCT with crossover PEDro=6 N=7	Population: SCI Group: Mean age: 37.1±7.7 yr; Sex: males=6, females=1; C5-T10 level injury, AIS A-C; mean time post-injury: 5.0±4.4 yr Intervention: Each participant underwent both	1. No significant difference in heart rate variability after either BWSTT or HUTT training. 2. There was ↑ sample heart rate complexity after

	BWSTT and head-up tilt training (HUTT) in random order, for 3 times/wk for 4wks, separated by a 4wk detraining period. Outcome Measures: Heart rate variability; heart rate complexity; fractal scaling distance score (the correlation of the time between heart beats).	BWSTT, whereas HUTT had no effect. 3. BWSTT, but not HUTT, reduced the fractal scaling distance score in participants.
Stevens & Morgan (2015) USA Pre-Post N=11	Population: SCI Group: Mean age: 48 yr; Sex: males=7, females=4; 6 adults with injuries at or above T5 and 5 adults with injuries below T5. Intervention: 8wks of Underwater Treadmill Training (UTT) (3 sessions/wk, 3 walking trials per session) incorporating individually determined walking speeds, personalized levels of body weight unloading, and gradual, alternating increases in speed and duration. In weeks 2, 4, 6, and 8, walking speed was increased by 10%, 20%, 30%, and 40% over baseline. Outcome Measures: Heart rate	1. None of the interaction tests involving injury level were statistically significant. When averaged over injury level, the interaction between training period and day was significant. 2. Pairwise comparisons revealed that from day 1 to day 6, heart rate fell by 7%, 14%, and 17% during training periods 1, 2, and 3. All participants exhibited significant ↓ in daily submaximal walking heart rate for each 2-week period.
Terson de Paleville et al. (2013) United States Pre-Post N=8	Population: Mean age: 37 yr; Sex: males=7, females=1; AIS-A tetraplegic; Mean time post injury: 25 mo. Intervention: Locomotor training (LT) with body weight support and treadmill 5 days/week for an average of 62 sessions. Outcome Measures: Forced vital capacity (FVC), forced expiratory volume (FEV1),	1. Significantly ↑ FVC, MIP, MEP, and FEV1 post-LT compared to pre-LT. 2. Significantly ↑ overall sEMG activity post-LT for all tasks. 3. 7 participants had ↑ sEMG amplitudes for all tasks post-LT. 4. No significant changes in distribution of sEMG activity post-LT for all tasks.

	maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), respiratory muscle surface electromyography (sEMG) and respiratory motor control assessment.	5. 1 subject developed activation in muscles post-LT which were not activated pre-LT. 6. Significantly faster muscle unit recruitment post-LT compared to pre-LT.
Soyupek et. al. (2009) Turkey Pre-Post N=8	Population: Incomplete SCI Group: Mean Age: 40. 8 ±13.9 yr (Range: 26-66 yr); Sex: males=6, females=2; Injury level C6-L1 Intervention: Body weight supported treadmill training (BWSTT), for 5 times/wk for 6 wks; length of training sessions ranged from 10 to 30 min Outcome Measures: Heart rate and blood pressure (BP); FEV1, FVC, inspiratory capacity, MIP, MEP.	1. Heart rate was significantly lower post-training compared to baseline. 2. There were significant improvements of the FVC and inspiratory capacity in participants post-training compared to baseline. 3. There were no significant differences in other parameters between pre- and post-training
Ditor et al. (2005) Canada Pre-Post N=6	Population: SCI Group: Mean Age: 37.7 yr; Sex: males=4, females=2; AIS A and B, C4-T12; Mean time post injury: 6.7 yr; motor complete. Intervention: Body weight supported treadmill training, 15 min/day (3 bouts of 5 min), 3 days/wk for 4 mo. Outcome Measures: BP, HR, HR variability, BP variability, arterial diameters and mean blood velocities, and arterial blood flow.	1. No changes in femoral or carotid artery cross sectional area or blood flow post-training. 2. An improvement in femoral artery compliance post-training. 3. No change in resting BP, mean arterial blood pressure, resting HR or HR and BP variability after training. 4. 3/6 patients had changes in HR and BP variability reflective of ↑ vagal dominance.
de Carvalho et al. (2006) Brazil Prospective Controlled Trial	Population: 21 male participants (C4 to C8), all complete with tetraplegia, mean age 32 ± 8 yrs. 11	1. Gait training (six months) resulted in significant ↑ in oxygen consumption (36%), minute ventilation (31%), and systolic blood pressure

Level 2 N = 21	assigned to the gait group and 10 controls. Intervention: BWSTT (30%–50%) with neuromuscular electrical stimulation 20 min/day, 2 days/wk for 6 mo. Control group performed conventional physiotherapy. Outcome Measures: BP, HR, oxygen uptake, carbon dioxide production, and minute ventilation (volume of gas entering lungs).	(5%) during the gait phase. In the control group, there were significant ↑ in resting oxygen consumption and carbon dioxide production (31 and 16%, respectively). 2. Gait training resulted in an ↑ aerobic capacity due to yielding higher metabolic and cardiovascular stress.
de Carvalho and Cliquet (2005) Brazil Pre-Post N = 12	Population: 12 male participants (C4 to C7), all complete with tetraplegia; Mean age = 33.8 yrs; Median time post-injury = 77.58 mos Intervention: BWSTT (30-50%) with neuromuscular electrical stimulation 20 min/day, 2 days/wk for 3 mos. Outcome Measures: BP and HR.	1. After training, increases in mean systolic blood pressure (94 ± 5 mmHg to 100 ± 9 mmHg) at rest and during gait exercise. 2. There were no significant changes in post-exercise BP after training.
Ditor et al. (2005) Canada Pre-post N = 8	Population: 8 participants (6 males, 2 females), AIS B-C, C4-C5, incomplete, mean age 27.6 yrs, mean 9.6 yrs post-injury. Intervention: Progressive, BWSTT, 3 day/wk for 6 mos. Outcome Measures: HR and BP variability, LF/HF ratio (indicative of sympathetic/parasympathetic tone).	1. Significant ↓ in resting HR (10.0%) after training. 2. No changes in resting systolic, diastolic, or mean arterial BP after training. 3. Significant reduction in the resting LF/HF ratio after training. 4. There were no significant effects of training on HR and/or BP variability during an orthostatic challenge (60° head up tilt).
Jack et al. 2009 (Jack et al. 2009) UK Case Series N = 2	Population: Participant A: female, T9 level injury, age 41 yrs, 2 yrs post-injury; Participant B: male, T6 level injury, age 40 yrs, 14.5 yrs post-injury	1. Both participant's VO_2 ↑ after exercise: participant A changed from 8.2 to 10.2 mL/kg/min; participant B changed from 13.8 to 18.2 mL/kg/min at week 17, after

	Intervention: BWSTT three 30-min sessions/wk for 16 wks (participant A) or 20 wks (participant B) Outcome Measures: Measures of cardiopulmonary fitness: oxygen uptake (VO_2); HR_{peak}; dynamic O_2 cost	which the VO_2 dropped back to 13.9 mL/kg/min. 2. HR_{peak} ↑ for both participants after training (89 to 119 bpm for participant A, 134 to 157 bpm for participant B). The dynamic O_2 cost ↓ for both participants (115 to 29.03 mL/min−1/W−1 for participant A, 66.57 to 4.52 mL/min−1/W for participant B).

Discussion

Seven BWSTT studies examined individuals with incomplete SCI, who engaged in active walking supported either above ground, or above treadmills with individually-determined body weight support. In general, there were small increases in cardiorespiratory fitness and improvements in submaximal heart rate, indicating a small degree of cardiovascular changes after 4-13 weeks of BWSTT.

Two RCT studies were completed for high-level evidence. Alexeeva et al. (Alexeeva et al. 2011) used an RCT design to evaluate two forms of body-weight supported walking (i.e., fixed track *vs*. treadmill) vs conventional physical therapy and observed small, but clinically meaningful improvements in VO_{2peak}. However, as these results were not statistically significant, some caution should be taken in their interpretation. Millar et al. (Millar et al. 2009) conducted a 4 week RCT with a cross-over design, but did not observe any improvements in heart rate variability, a marker of autonomic nervous system function. They did indicate improvements in heart rate complexity, another marker of autonomic function. Changes in nervous system function were also noted by Ditor et al. (Ditor et al. 2005), who indicated improvements in heart rate variability after 6 months of BWSTT.

There is good evidence to indicate improved respiratory function after BWSTT in individuals with incomplete SCI. Both Terson de Paleville et al. (2013) (12 week BWSTT) and Soyupek et al. (2009) (6 week BWSTT) demonstrated improvements in forced vital capacity after training, which measures the total amount of air exhaled during a maximal breathing effort. Both studies were pre-post designs with small sample sizes, but provide corroborating findings for respiratory improvements after BWSTT.

Three studies examined individuals with motor-complete SCI, using completely passive gait training in the upright position. Ditor et al. (2005) did not observe improvements in cardiorespiratory fitness, although there were small effects on markers of lower-limb vascular health. de Carvalho & Cliquet (2005) indicated increased blood pressure control after 3 months of BWSTT, while de Carvalho et al. (2006) indicated improved submaximal exercise capacity after 6 months of passive BWSTT, as noted by increase in exercise oxygen consumption (VO_2), ventilation and exercise blood pressure.

Five studies used robotic-assisted body-weight supported treadmill training (RABWSTT), with active initiation of gait. Gorman et al. (2019) used a RCT design to evaluate the efficacy of robotic (exoskeleton) therapy or aquatic therapy to increase cardiorespiratory fitness. Exoskeleton training was not able to increase VO_{2peak} during conventional maximum arm ergometry testing, but was able to increase mode-specific VO_2 during exoskeleton walking sessions. Similarly, Gorman et al. (2016) demonstrated increase in VO_2 during RABWSTT-specific training. Hoekstra et al. (Hoekstra et al. 2013) used a 24-session pre-post design to evaluate fitness in individuals with incomplete SCI. No differences were observed in submaximal VO_2 post-intervention, though improvements in submaximal heart rate and resting heart rate were observed. While Turiel et al. (Turiel et al. 2011) indicated improvements in diastolic heart function after 6 weeks of RABWSTT, they did not report translations into improved cardiorespiratory fitness. Finally, in the only positive study, Cheung et al. (2019) used an RCT design to indicate improvements in cardiorespiratory fitness after 8 weeks of RABWSTT; however, the magnitude of improvement was so small it would be considered negligible in a functional capacity.

Conclusion

There is Level 1b evidence (Millar et al. 2009) that at least 1 month of 3x/week BWSTT can improve autonomic nervous system function.

There is Level 4 evidence (Jack et al. 2009) that 16 weeks of 3x/week BWSTT can improve VO_{2peak}.

There is Level 4 evidence (Stevens et al. 2015) that 8 weeks of 3x/week BWSTT can improve submaximal exercise capacity.

There is Level 4 evidence (Soyupek et al. 2009; Terson de Paleville et al. 2013) that 6 weeks of 5x/week BWSTT can improve respiratory function.

There is Level 4 evidence (de Carvalho & Cliquet, 2005; de Carvalho et al. 2006; Ditor et al. 2005) that at least 3 months of passive BWSTT can improve aspects of cardiovascular function in individuals with motor-complete injuries.

3.1.5 Exoskeleton Training

Exoskeleton assist devices support body movements by containing the lower limbs within a rigid scaffold with motorized joints to support and assist limb movement during physical efforts. Modern exoskeleton systems are able to provide reactive support, only engaging mechanical joints to assist movement (i.e., active movement) rather than initiate joint movements (i.e., passive movement). Exoskeleton systems can be used to assist overground walking in individuals with preserved locomotor function, or can be paired with treadmill or BWSTT systems to partially support body weight to accommodate non-weight bearing individuals. The available evidence supporting exoskeleton devices for improvement in cardiorespiratory fitness comes from a combination of over-ground and over-treadmill walking, summarized below.

Table 5. Effect of Exoskeleton Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Gorman et al. (2019) USA RCT Crossover PEDro=7 NInitial=37, NFinal=31	Population: Mean age robotic group: 46.9 yrs. Mean age aquatic group: 45.4 yrs. Level of injury: C2-T12; Level of severity: AIS C, AIS D. Intervention: Individuals were randomized to either robotic therapy (RT; n = 18) or aquatic therapy (AT; n = 15). RT used a robotic-assisted body-weight supported treadmill device. First session was 20min, then ↑ by 5min in subsequent visits until the duration reached 45min 3 days/wk for a total of 36 sessions. AT consisted of three, 45min sessions/wk. Water positioning (standing, sitting, horizontal, depth),	1. VO_{2peak} measured with arm ergometry was not significantly different with either aquatic intervention (p=0.14) or robotic intervention (p=0.31). 2. VO_{2peak} during robotic treadmill ergometry demonstrated a statistical increase (p=0.03). 3. Comparison between the two interventions demonstrated a trend favoring aquatic therapy for improving arm ergometry VO_{2peak} (p=0.063).

	floatation and resistance devices were used. Outcome Measures: Heart rate (HR), peak oxygen consumption (VO_{2peak}).	
Gorgey et al. (2017) USA Case Series N=4	Population: SCI: Mean age: 44.75yr; Gender: males=4, females=0; Level of injury: C5=2, T4=2; Injury severity: AIS A=3, AIS D=1. Intervention: Participants took part in a clinical rehabilitation program, in which they walked once weekly using an overground powered exoskeleton for approximately 1h for 10-15wk. Outcome Measures: Walking time, stand up time, ratio of walking-to-stand up time, number of steps; oxygen uptake (VO_2), energy expenditure, and body composition were measured in one participant after training.	1. Over the course of 10 to 15wk, the maximum walking time ↑ from 12 to 57 minutes, and the number of steps ↑ from 59 to 2,284 steps. 2. At the end of the training, all four participants were able to exercise for 26 to 59min. 3. For one participant, oxygen uptake ↑ from 0.27 L/min during rest to 0.55 L/min during walking. 4. Delta energy expenditure ↑ by 1.4 kcal/min during walking.
Hoekstra et al. (2013) Netherlands Pre-post N=10	Population: Mean age: 49 yrs; Sex: males=4, females=6; Level of severity: AIS C=6, AIS D=4; Time since injury: <1yr=2, 1-5yr=3, >5yr=5. Intervention: Participants received robot-assisted gait training using a robotic-assisted body-weight supported treadmill device (24 sessions total, 2-3 sessions/wk, 60min each) and physical therapy completed within 10 to 16wk. Outcome Measures: Graded arm crank exercise test, Robotic walking test, VO_2 and O_2 pulse.	1. No significant differences in submaximal VO_2 between pre- and post-test were found, but submaximal HR was significantly lower after the training program. 2. Resting heart rate was significantly lower at post-test than pre-test. 3. No changes were found in VO_2 robot and HR robot pre- to post-training.
Turiel et al. (2011) Italy	Population: SCI Group: Mean age 50.6 ± 17.1 yrs; Sex:	1. Significant improvement in left ventricular diastolic

Pre-Post N=14	males=10, females=4; 2-10 yrs post-injury; 9 paraplegia) with lost sensorimotor function caused by incomplete SCI. Intervention: Robotic-assisted body-weight supported treadmill training for 60 min sessions, 5 days/wk, 6 wks, with 30-50% of body weight supported (reduced as tolerated). Outcome Measures: Left ventricular function, coronary blood flow reserve (via dipyrsidamole stress echo), plasma asymmetric dimethylarginine (ADMA), and plasma inflammatory markers.	function (i.e., a reduction in isovolumic relaxation time and deceleration time was observed following the training). 2. Significant ↑ in coronary reserve flow and reduced plasma ADMA levels were observed in the follow-up. 3. Significant reduction in the inflammatory status (C-reactive protein and erythrocyte sedimentation rate).
Cheung et al. (2019) Hong Kong RCT PEDro=8 N=16	Population: Incomplete SCI; Robotic-assisted body weight supported treadmill training (RABWSTT) Group (n=8): Mean age: 55.6 yrs; Sex: males=7, females=1; Level of injury: C1-L2; Mean time post injury: 17.0 mo. *Control Group (n=8):* Mean age: 53.0 yrs; Sex: males=4, females=4; Level of injury: C3-L2; Mean time post-injury: 10.4 mos. Intervention: Participants were randomly allocated into an intervention group or control group. The intervention group received 30 min of RABWSTT with EMG biofeedback system over the vastus lateralis muscle to enhance active participation. Training was 3 times/wk for 8 wks. Dose equivalent passive lower limbs mobilization exercise was provided to subjects in the control group.	1. Significant time-group interaction was found in the WISCI II (p=0.02), SCIM III mobility sub-score (p < 0.001), bilateral symmetry (p=0.048), maximal oxygen consumption (p=0.014) and peak expiratory flow rate (p=0.048). 2. Compared to the control group, the intervention group showed significant improvements in the above-mentioned outcomes after the intervention (p<0.025), except WISCI II.

	Outcome Measures: Walking Index for Spinal Cord Injury version II (WISCI II), Spinal Cord Independence Measure version III (SCIM II), lower limb muscle strength (Lower Extremity Motor Score; LEMS), Isometric muscle strength of hips and knees, Modified Ashworth Scale, hip and knee flexors and extensors, joint stiffness, passive hip and knee joint movements in different speeds, resistive torque, quality of gait pattern, VO_{2peak}, peak expiratory flow (PEF), forced expiratory volume in the first second (FEV1) and forced vital capacity (FVC).	
Gorman et al. (2016) USA RCT PEDro=6 N=18	Population: Incomplete SCI: n=18; between C4 and L2; >1yr post injury. Intervention: Participants were randomized to Robotic-Assisted Body-Weight Supported Treadmill Training (RABWSTT) or a home stretching program (HSP) 3 times per week for 3 mos. Those in the home stretching group were crossed over to three months of RABWSTT following completion of the initial 3 mo phase. Outcome Measures: VO_{2peak} was measured during both robotic treadmill walking and arm cycle ergometry: twice at baseline, once at 6wks (mid-training) and twice at 3mo (post-training). VO_{2peak} values were normalized for body mass.	1. The RABWSTT group improved VO_{2peak} by 12.3% during robotic treadmill walking (20.2 ± 7.4 to 22.7 ± 7.5 ml/kg/min, P = 0.018). 2. VO_{2peak} during robotic treadmill walking and arm ergometry showed statistically significant differences.

Discussion

The general observations from the available exercise training studies indicates that exoskeleton-assisted exercise training primarily improves exercise capacity in exoskeleton-specific movements and its improvements do not largely translate to central cardiovascular fitness as determined by conventional arm cycling tests. Five studies employed over-treadmill exoskeleton-assisted walking, and one study used over-ground exoskeleton-assisted walking. By nature of the intervention, all participants engaged in active walking (i.e., the exercise was not passively guided).
In a case series, Gorgey et al. (2017) indicated that over-ground exoskeleton training was feasible in a small group of individuals undergoing a clinical rehabilitation program, providing support that mode-specific exercise capacity can improve with only one hour of exoskeleton training per week for greater than 10 weeks.

Conclusion

There is Level 1 evidence (Gorman et al. 2019; Gorman et al. 2016) that 3 months of exoskeleton exercise training can improve exoskeleton-specific exercise capacity.

There is Level 4 evidence (Gorgey, Wade, et al. 2017) that 10 weeks of exoskeleton exercise training can increase exoskeleton walking time and walking duration.

There is Level 4 evidence (Hoekstra et al. 2013) that 10 weeks of exoskeleton exercise training can increase submaximal heart rate and lower resting heart rate.

3.1.6 Other Physical Activity

Other forms of activity can elicit therapeutic effects on health and/or fitness. These other forms of physical activity might be performed for a different purpose (such as sport, for the social and fun aspects, or the desire to compete), yet these activities can also benefit health and/or fitness as an unintended outcome. We categorize interventions as “other” if the activity was not restricted to a specified mode (e.g., “behaviour change”, “general rehabilitation” or “multi-modal”), was sport-related, or the mode was deemed to be an uncommon form of prescribed exercise (e.g., over-ground ambulation for individuals with incomplete injuries, recumbent stepper, simulated wheelchair rolling exercise, passive leg-cycling etc.).

Table 6. Effect of Other Forms of Physical Activity and Exercise Training on Cardiovascular Health and Endurance

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	Behaviour Change Interventions	
Williams et al. (2021) Canada RCT PEDro=6 $N_{initial}$=32 N_{final}=28	Population: *Intervention Group (IG):* Age=45.8±13.6yr; Gender: males=9, females=5; Level of injury: C1-T6=8, Below T6=6; Level of severity: AIS A=7, B-D=1, Not reported=6; Time since injury=14.7±13.9yr. *Control Group (CG):* Age=45.6±10.5yr; Gender: males=8, females=6; Level of injury: C1-T6=9, Below T6=5; Level of severity: AIS A=6, B-D=3, Not reported=5; Time since injury=18.1±10.9yr. Intervention: Participants were randomized to either an an 8-week behavioural physical activity intervention (n=14) or a control group (n=14). Outcome Measures: Resting Left Ventricular (LV) Structure and Function, Posterior Wall Thickness (PWT), Blood pressure, Common Carotid Artery Intima-Media Thickness (CCA-IMT) and Pulse-Wave Velocity (PWV) were assessed with Ultrasound and Tonometry, respectively. VO_{2peak} & PO_{peak} were determined via a cardiopulmonary exercise test on an arm-crank ergometer.	*Resting Cardiovascular Structure and Function* 1. No significant group, time, or interaction effects for LV volumes, hemodynamics, or LV geometry ($p>0.05$ for all), despite significant improvements in VO_{2peak} and PO_{peak} ($p<0.05$). 2. For diastolic measures, only E' ($p=0.008$) and A' ($p=0.025$) were significantly lower at post-intervention in the IG, but not in the CG. 3. No effects for LV twist mechanics, although untwisting velocity was significantly elevated in the IG compared to the CG ($p=0.014$). 4. No significant change in PWT or CCA-IMT at post-intervention or between groups ($p>0.05$). 5. No significant effects for blood pressure. *Sub-Analysis for Level of Injury (LOI)* 1. No significant changes in cardiovascular structure or function detected at post-intervention in the high-LOI group, but there were significant ↑ in LV end-diastolic internal diameter

		(LVID) and reductions to sphericity in the low-LOI PA group at post-intervention (p=0.027 and p=0.049, respectively). 2. No other significant effects in the low- or high-LOI groups for measures of LV mechanics, Doppler velocities, IMT, PWV, or blood pressure. 3. Both high- and low-LOI cohorts had significant group × time interactions for relative VO_{2peak} (p=0.002 and p=0.006, respectively) and PO_{peak} (p=0.01 for both cohorts). 4. ↑ in self-reported total PA (p=0.99) and moderate-to-vigorous PA (p=0.30) were not different between the high- and low-LOI PA cohorts.
Nooijen et al. (2017) The Netherlands RCT PEDro=6 $N_{Initial}$=45; N_{Final}=39	Population: *Intervention group:* Mean age: 44 yr; Gender: males=17, females=3; Level of injury: Tetraplegia=7, Paraplegia (13); Mean time post-injury: 139 days. *Control group:* Mean age: 44 yr; Gender: males=16, females=3; Level of injury: Tetraplegia=6, Paraplegia=13; Mean time post-injury: 161 days Intervention: *Intervention group:* A behavioural intervention promoting physical activity, involving 13 individual sessions delivered by a lifestyle coach who was trained in motivational interviewing. The intervention began 2 mo. before and ending 6 mo. after discharge from inpatient rehabilitation. *Control group:* Regular rehabilitation	1. Diastolic blood pressure improved significantly 12 months after discharge (p=0.01), 2. Total cholesterol (p=0.01) and low-density lipoprotein cholesterol (p=0.05) improved significantly 12 months after discharge 3. Participation improved significantly 12 months after discharge (p<0.01). 4. There seemed to be a clinically relevant between-group difference for peak power output, BMI and general health perceptions; however, the differences between the groups were not statistically significant

	Outcome Measures: Physical capacity as determined during a maximal handcycle exercise test, body mass index (BMI), blood pressure, fasting lipid profile, social participation (IMPACT-S), 36-item Short Form Health Survey questionnaire (SF-36).	(p>.05).
Ambulation/Stepping Training for Individuals With Motor-Incomplete Injuries		
Lotter et al. (2020) USA Randomised Crossover PEDro=6 $N_{Initial}$=17, N_{Final}=15	Population: *Impairment-Based First Group (n=8):* Mean age: 51±17yr; Gender: males=6, females=2; Level of injury: C1-C4=4; C5-C8=2 T1-T10=2; Severity of injury: Incomplete (AIS C or D)=8; Mean time since injury: 3.9±1.8yr; *Task-Specific Frst Group (n=8)*: Mean age: 46±13yr; Gender: males=4, females=4; Level of injury: C1-C4=2; C5-C8=2 T1-T10=4; Severity of injury: Incomplete (AIS C or D)=8; Mean time since injury: 4.3±4.3yr. Intervention: Participants performed either task-specific (upright stepping) or impairment-based training for up to 20 sessions over ≤6wks, with interventions alternated after >4wks delay. Both strategies focused on achieving higher cardiovascular intensities, with training specificity manipulated by practicing only stepping practice in variable contexts or practicing tasks targeting impairments underlying locomotor dysfunction (strengthening, balance tasks, and recumbent stepping). Outcome Measures: Primary outcome measures were fastest speed over short distances and peak treadmill speed. Secondary outcome measures were self-selected speed on the	1. Significantly greater increases in fastest overground and treadmill walking speeds were observed following task-specific versus impairment-based training (p's≤0.01). 2. Gains in balance confidence were observed following task-specific vs. impairment-based training (p=0.02), although incidence of falls was increased with the former protocol (3 vs. 0). 3. A significant time × training interaction was observed for changes in peak recumbent stepping power favoring impairment-based vs task-specific training, (27±45 vs −0.20±33 watts; p=0.04) 4. For secondary metabolic measures, there was a significant main effect of time only for VO_{2peak} during treadmill exercise tests but not for recumbent stepping tests, with no significant interactions.

	instrumented walkway with instructions to “walk at your normal, comfortable pace,” and a six minute walk test with instructions to “cover as much ground as possible”. Other outcome measures included Berg Balance Scale, 5-times sit-to-stand, Activities-specific Balance Confidence scale, Patient-Reported Outcomes Measurement Information System–Mobility score (version 1.2), lower extremity motor score, VO_{2peak} during graded exercise tests on the treadmill and peak power and VO_{2peak} during a graded recumbent stepping test.	
Wouda et al. (2018) Norway RCT PEDro=7 N=30	Population: Mean age: 41yr; Gender: males=25, females=5; Level of injury:C1-C8, T1-T12, L1-L5, S1-S5; Time since injury: 69 days. Intervention: Participants were randomized into one of the three groups: high-intensity interval training (HIIT) group, moderate-intensity interval training (MIT) group, or a control group (treatment as usual). The HIIT program was 35min, 2x/wk; 10min warm-up at 70% of peak heart rate (HR_{peak}) followed by 4 × 4min intervals at an intensity of 85–95% of HR_{peak} interspersed with 3 × 3 min recovery periods at an intensity of 70% of HR_{peak}. The MIT program consisted of 45min of continous walking or running (depending on their physical ability), 3x/wk at an intensity of 70% of HR_{peak}. Those in control group did not receive any aerobic exercise prescriptions.	1. VO_{2peak} ↑ from the pre- to post on average 13±17%, 8±13%, and 10±7% in the HIIT, MIT and control groups, respectively. Similarly, the distance walked during the 6MWT ↑ on average by 18±11%, 15±16%, and 9±15%, respectively. There were no statistically significant differences in changes pre- to post-intervention between the groups, after controlling for the pre-test values in either VO_{2peak} (ANCOVA: p=0.94) or 6MWT (p=0.58). 2. Total daily energy expenditure (TDEE) ↑ from the pre- to post-intervention on average 7±11%, 1±15%, and 5±10% in the HIIT, MIT and control groups, respectively. The MIT and control group had a ↓ daily number of steps

	Outcome Measures: VO_{2peak}, respiratory exchange ratio (RER), HR_{peak}, blood lactate, 6-min walking test (6MWT). Physical activity levels were assessed via the International Physical Activity Questionnaire (IPAQ).	on average −1±54% and −1±39%, while the HIIT group showed an average ↑ of 16±18%. There was no significant effect of group on the changes in physical activity levels indicated by TDEE (p=0.79) and daily number of steps (p=0.63).
DiPiro et al. (2016) USA Pre-Post $N_{Initial}$=10, N_{Final}=9	Population: Mean age: 57.94±9.33 yr; Gender: males=5, females=5; Level of injury: Cervical=9, Thoratic=1; Severity of injury: AIS C=1, AIS D=9; Mean time since injury: 11.1±9.6yr. Intervention: Participants completed voluntary, progressive moderate-to-vigorous intensity exercise on a recumbent stepper (3d/wk for 6wks). Outcome Measures: Primary outcome measures: Aerobic capacity (VO_{2peak}) and self-selected overground walking speed (OGWS). Secondary Outcome Measures: walking economy, 6-minute walk test, daily step counts, Walking Index for Spinal Cord Injury, Dynamic Gait Index and Berg Balance Scale.	1. Aerobic capacity improved significantly from pre- to post-intervention (p=0.011). 2. OGWS improved significantly from pre- to post-intervention (p=0.023). 3. The percentage of VO_{2peak} used while walking at self-selected speed improved significantly from pre- to post-intervention (p=0.03). 4. Daily step counts improved significantly from pre- to post-intervention (p=0.025).
General Sport Training Interventions		
Sarro et al. (2016) Brazil Pre-Post $N_{Initial}$=10, N_{Final}=7	Population: Mean age: 26.86±5.87yr; Gender: males=10, females=0; Level of injury: C1-T1=10, T2-L5=0; Mean time since injury: 90.86±55.80mo. Intervention: Regular wheelchair rugby training, consisting of 3-4 session/wk for 2hr/session. Training load was according to the competition schedule, following the	1. During quiet breathing, significant differences were found for tidal volume (p=0.04), superior thorax (p=0.04) and inferior thorax (p=0.01) mobility, representing ↑ of 16.9%, 61.3% and 83.7%, respectively. 2. During maximal breathing, significant differences and

	traditional annual model divided in preparatory, competition and transition period. Training lasted 1yr. Outcome Measures: Lung volume and tridimensional mobility of four-chest wall compartments (superior and inferior thorax, superior and inferior abdomen).	large effect sizes were found for vital capacity (p=0.01) and superior thorax (p=0.04) mobility, representing ↑ of 24.8 and 31.5%, respectively.
Matos-Souza et al. (2016) Brazil Prospective Observational N=17	Population: *Sports Group (n=8);* Mean Age=28.3±2.5yr; Gender: Males=8, Females=0; Level of Injury: C5-T9; Severity of Injury: AIS A=7, B=1; Mean Time Since Injury=5.1±1.3yr. *Control Group (No Sports; n=9);* Mean Age=33.7±2.2yr; Gender: Males=9, Females=0; Level of Injury: C4-T8; Severity of Injury: AIS A=8, B=1; Mean Time Since Injury=7.6±1.5yr. Intervention: Not applicable. Prospective observational study to determine whether involvement in adapted sports is associated with long-term changes in carotid atherosclerosis in individuals with SCI. Outcome measures were assessed at baseline and 5yr follow-up. Outcome Measures: Cholesterol, triglycerides, c-reactive protein, blood pressure, heart rate, stroke volume, cardiac output, peripheral vascular resistance, carotid ultrasonography.	1. At follow-up the control group experienced: significant ↑ in resting heart rate (p=0.004) and no significant changes in carotid intima-media thickness or diameter (p>0.05). 2. At follow-up the sports group experienced: significant ↓ in carotid intima-media thickness (p=0.001) and diameter (p<0.001). No other variables were significantly different at follow-up.
Moreno et al. (2013) Brazil Pre-Post and cross-sectional comparison	Population: N=15 male tetraplegic individuals with SCI divided into a control (n=7) and rugby player (n=8) group. Control group: mean±SD age: 33±9yr; DOI: 73±53 months.	1. There was a significant ↑ in all variables after training: (mean±SD) FVC ↑ from 2.7±0.9 L to 3.0±1.0 L. 2. FEV1 ↑ from 2.5±0.9 to 2.8±1.0 L.

N=15	Rugby player group: mean±SD age: 26± 6 yr; DOI: 87±52 months. Intervention: Experimental group participated in a regular 1-year wheelchair rugby training program that involved stretching, strength exercises, and cardiovascular resistance training (2-hour sessions, 3-4x per week). The control participants were only assessed once at baseline. Outcome Measures: forced vital capacity (FVC), forced expiratory volume measured during the first phase (FEV1) and maximal voluntary ventilation (MVV).	3. MVV ↑ from 107±28 to 114±24 L/min. 4. No significant difference between the control group and rugby players regarding spirometric variables, except for MVV, which was higher in rugby players.
Fukuoka et al. (2006) Japan Pre-Post N=8	Population: N=8 (7M 1F); mean±SD age: 46.5±8.3yrs; AIS B; T7-L1. Intervention: Wheelchair training program: 30 min at 50% HRR, 3x/wk, for 60 days. Outcomes were assessed before training, after 7, 15, 30 and 60 days of training Outcome Measures: VO_{2peak}, HR.	1. Mean VO_{2peak} ↑ with training, became significant from 30th training day onwards (baseline = 17 ml/kg/min vs. T30 = 18 ml/kg/min). 2. Steady state HR assessed during the constant workload test (50% of VO_{2peak}) ↓ significantly by the 7th training day and plateau from day 15 onwards (baseline HR = 123±11 bpm, day 7 = 112±11 bpm, day 15 = 109±6 bpm).
General Rehabilitation		
Nooijen et al. (2012) Netherlands Observational N=30	Population: Mean age: 42yr; Gender: 72% males; Injury: 53% tetraplegia, 72% motor-complete SCI; Mean time of inpatient rehabilitation: 7mo. Intervention: Outcomes were assessed at 4 timpeoints : start of active rehabilitation (t1), 3 months later (t2), at discharge	1. After correcting for confounding variables, physical activity level was significantly correlated to VO_{2peak} and PO_{peak} ($p<0.01$). An ↑ in physical activity level was associated with an ↑ in aerobic capacity. 2. With regard to lipid profile, an ↑ in activity level was

	from inpatient rehabilitation (t3), and 1 year after discharge (t4) Outcome Measures: VO_{2peak}, PO_{peak}, Isometric muscle strength, Lipid profile (cholesterol, triglycerides) and physical activity level (assessed via an accelerometery-based activity monitor).	correlated to a ↓ in concentration of TG (P<0.01) and to a ↓ in TC/HDL ratio (P<0.05). 3. Corrected for confounders and time, an ↑ in physical activity level of 26 min day was associated with an ↑ in 0.11 L min (ß=0.059*1.79%) in VO_{2peak}. The same ↑ of 26 min day, corrected for confounders and time, was associated with an ↑ in PO_{peak} of 4.06W (ß=2.27*1.79%), a ↓ in TG of 0.14 mmol (ß=0.076*1.79%) and a ↓ in TC/HDL ratio of 0.23 (ß=0.127*1.79%).
Valent et al. (2008) The Netherlands Observational N=137	Population: SCI participants: C5 or lower; aged 18-65yrs. *Hand cycling group:* 35 participants with paraplegia, 20 with tetraplegia. *Non-hand cycling group:* 56 with paraplegia, 26 with tetraplegia. Intervention: All participants followed the usual care rehabilitation program in their own rehabilitation centres, with or without regular hand cycling exercise. Study included three measurements: 1) when participants could sit in a wheelchair for three hours; 2) on discharge; 3) 1 year after discharge. Outcome Measures: VO_{2peak}; FVC; peak expiratory flow rate (PEFR).	1. Significant ↑ (26% in hand cycling group vs. 8% non-hand cycling group) in VO_{2peak} in paraplegic patients, whereas tetraplegic patients showed no change. 2. No change in pulmonary function (FVC or PEFR) found in either participants with paraplegia or tetraplegia.
Grange et al. (2002) France Pre-Post N=14 (SCI=7)	Population: *Able-bodied (n=7):* Mean age: 26.6yr; Gender: males=7. *SCI (n=7):* Mean age: 35.2yrs; Mean time since injury: 12.3yrs; Gender: males=7; Level of injury: paraplegia; Level of severity: AIS A.	1. There was no significant difference in both groups for PE between the two GXT (p>0.05). However, a significant ↓ in the PE values (p<0.01) was

	Intervention: All individuals participated in a rehabilitation program composed of 3 sessions/wk for 6wk. Each session consisted of a 45 min Square Wave Exercise Tests (SWEET). During each work bout, a 4 min period of moderate work (base level) was followed by a 1 min period of heavy work (Peak level). The maximal graded exercise tests (GXT) and the SWEET were performed before (GXT 1 and SWEET 1) and after a 6 wk training period (GXT 2 and SWEET 2). Outcome Measures: VO_{2peak}, maximal tolerated power (MTP), heart rate and perceived exertion (PE).	observed in both groups during the SWEET 2. 2. There was no significant difference in HR_{max} between the two GXT, but a significant ↓ in HR ($p<0.0001$ for baseline HR and $p<0.001$ for HR_{peak}) was observed in SWEET 2 compared to SWEET 1. 3. The MTP and VO_{2peak} ↑ significantly in able-bodied ($p<0.0001$) and paraplegic groups ($p<0.05$).
Multi-Modal Training		
Kim et al. (2019) Korea RCT PEDro=6 $N_{Initial}=19$, $N_{Final}=17$	Population: Mean Age=36.8±6.9yrs; Gender: Males=11, Females=6; Level of Injury: L1-C4; Severity of Injury: AIS A=9, B=7, C=1; Time Since Injury ≥1yr. Intervention: Participants were randomized to complete a combined exercise program consisting of aerobic and resistance exercises (60 min/d, 3 d/wk for 6 wk) or usual care. The exercise program consisted of the following: 25-min warm-up consisting of 5-min of joint exercises, 15-min of exercise on an arm-crank ergometer, and 5-min of stretching, followed by a 30-min exercise program (resistance training circuit and aerobic training), and a 5-min of cooldown (stretching). Circuit and aerobic exercise was performed at a moderate-to-	1. Compared to usual care, the exercise program significantly: ↓ the mean fasting insulin, ↓ HOMA-IR, ↑ HDL cholesterol, ↓ waist circumference, and ↑ muscle strength of the shoulder flexors, extensors, adductors, abductors, and elbow flexors (group × time interactions $P<0.05$). 2. There were no significant (group × time interactions ($p>0.05$) on measures of: VO_{2peak}, lean mass, body fat percentage, total cholesterol and LDL cholesterol.

	vigorous intensity (4-8 on a Borg CR10 scale). Outcome measures were assessed at baseline and 6 wk. Outcome Measures: VO_{2peak}, body mass index, percent body fat, waist circumference, shoulder abduction /adduction, shoulder flexion/extension, elbow flexion/extension, fasting insulin levels and homeostasis model assessment of insulin resistance (HOMA-IR) levels.	
Yarar-Fisher et al. (2018) USA RCT PEDro=5 $N_{Initial}$=20, N_{Final}=11	Population: Mean age: 46.0±7.8yrs; Gender: males=10, females=1; Level of injury: C1-T1=4, T2-L5=7; Level of severity: AIS A=3, AIS B=8; Mean time since injury: 21.8±6.3yrs. Intervention: Isocaloric high-protein (HP) diet vs. a multi-modal exercise intervention, which consisted of upper-body resistance training (RT) in addition to neuromuscular electrical stimulation (NMES)-induced-RT for paralytic Vastus Lateralis muscle. Strength training was combined with high-intensity arm-crank exercises for improving cardiovascular endurance. Exercise training was completed 3 days/wk for 8 wk. Outcome Measures: Dual-energy X-ray absorptiometry scan, VO_{2peak}, and maximum voluntary upper-body strength.	1. VO_{2peak} significantly ($P<0.05$) ↑ from 13.2±3.4 to 14.6±3.3 ml/kg/min. 2. Upper-body strength (arm-curl, overhead press, chest fly and lat pull down) significantly ($P<0.05$) ↑.
Gant et al. (2018) USA Pre-Post N=8	Population: Mean age=31.4yrs; Gender: males=6, females=2; Time since injury: 10.5yrs; Level of injury: T2 - T10; Severity of injury: AISA A=4, B=4. Intervention: Participants underwent three, 4-wk long	1. No significant differences in neurological motor and sensory impairment, blood pressure, cholesterol, lipids, biomarkers of glycemic control and inflammation,

	multi-modal exercise conditioning and rehabilitation interventions, each separated by a one wk period of multiple body systems assessments. Each participant was in the trial for 19 continuous weeks. Outcome measurements were assessed after screening for two baseline assessments and at 4, 9, 14 and 19 wk. Outcome Measures: Neurological motor and sensory impairment; Upper-extremity muscle strength; VO_{2peak}; Blood pressure; cholesterol, lipids and biomarkers of glycemic control and inflammation; Clinical and electrophysiological spasticity measures; Pain history and pain-related sensory function; Self-reported function; Patient-reported global impression of change.	as well as chronic pain were observed ($p>0.05$). 2. Upper-extremity muscle strength significantly improved from baseline ($p=0.001$). 3. VO_{2peak} was not significantly different from baseline ($p>0.05$). 4. Two participants experienced clinically significant improvements in self-reported function ($p<0.05$). All participants reported a perceived improvement.
Totosy de Zepetnek et al. (2015) Canada RCT PEDro=4 $N_{initial}=23$ $N_{final}=17$	Population: *SCI-specific Physical Activity Guidelines (PAG) for improving fitness:* Age=39±11yr.; Gender: males=12, females=0; Level of injury: C3-T10; Level of severity: AIS A-B=3, C-D=9; Time since injury=15±10yr. *Control Group* Age=42±13yr.; Gender: males=9, females=2; Level of injury: C1-C11; Level of severity: AIS A-B=5, C-D=6; Time since injury=9±10yr. Intervention: Participants were randomized to receive SCI-specific physical activity guidelines (PAG) for improving fitness or active control (CON). PAG training was 2x/wk for 16wk and involved 20min of aerobic exercise at a moderate-to-vigorous intensity (RPE 3–6 on 10-point scale) and three sets of	*Traditional CVD Risk Factors and Blood Biomarkers:* 1. No change in HbA1c, lipids, fasting insulin, adipokines, proinflammatory markers, and thrombotic markers in either group. *Body Composition* 1. There was a group × time interaction for WBM ($p=0.03$), WBF ($p=0.04$), and VAT ($p=0.04$). 2. Trend toward an interaction for LF ($p=0.056$). 3. Group × time interaction for WC ($p=0.03$) and BMI ($p=0.02$). 4. No changes observed in WBL mass. *Arterial Structure and Function*

	10 repetitions (at 50–70% 1 repetition maximum). The control group maintained existing physical activity levels with no guidance on training intensity Outcome Measures: Blood biomarkers; glycosylated hemoglobin (HbA1c), lipids (triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, total cholesterol/high-density lipoprotein cholesterol), fasting insulin, adipokines (leptin, adiponectin), proinflammatory markers (IL-6, TNF-α), and prothrombotic markers (PAI-1), Body composition; whole body mass (WBM), leg fat (LF), body mass index (BMI), waist circumference (WC), whole-body fat (WBF), whole-body lean (WBL), and visceral adipose tissue (VAT), Arterial structure and function; Heart rate (HR) and blood pressure (BP) were monitored continuously, Carotid pulse pressure (CPP), carotid distensibility (CD), intima media thickness (IMT), lumen diameter (LD), and wall-to-lumen ratio (WLR), central and peripheral (arm, leg) pulse wave velocity (PWV), brachial (BA) and superficial femoral artery (SFA) endothelial-dependent (flow-mediated dilation [FMD]) and endothelial-independent (NTG) vasodilation.	1. Group × time interaction was found for CD (p=0.05). 2. No interactions were found for other measures of carotid artery structure (CPP, IMT, WLR), indices of regional stiffness (central, arm, leg PWV), or vascular function (BA, SFA, endothelial dependent [FMD] or independent [NTG] vasodilation).
Pelletier et al. (2015) Canada RCT	Population: Mean age: 40.4yrs; Gender: males=21, females=2; Level of injury: C1-T11=23; Time post injury: 12.0yrs.	1. There was a significant group × time interaction for relative (p=0.01) and absolute (p=0.004) VO_{2peak}, indicating ↑ aerobic

PEDro=4 N=23	Intervention: Participants were randomized to receive SCI-specific physical activity guidelines (PAG) for improving fitness or active control (CON). PAG training was 2x/wk for 16wks and involved 20-min of aerobic exercise at a moderate-to-vigorous intensity (RPE 3–6 on 10-point scale) and three sets of 10 repetitions (at 50–70% 1 repetition maximum). Participants in the CON group were members in a twice weekly community exercise program geared for adults with SCI. Outcome Measures: VO_{2peak}, Central and peripheral RPE (Borg 10- point scale), Heart rate (HR), Satisfaction with the guidelines and strength.	capacity in the PAG group following training. While there was a 13.4% ↑ in PO_{peak} in the PAG group following training, it did not reach statistical significance (p=0.059) 2. Post training, the PAG group completed a submaximal exercise test at a higher power output than the CON group (p=0.01). 3. There was a significant group × time interaction for vertical bench press (p=0.02), seated row (p=0.03) and elbow extension (p<0.01), reflective of mean strength ↑ in the PAG group of 7.3 ± 6.4 kg, 8.3 ± 6.1 kg and 22.5 ± 23.1 kg, respectively. 4. Satisfaction with both the aerobic (6.3± 0.64) and resistance (6.7± 0.5) aspects of the PAG training protocol were high (maximum score of 7). Enjoyment of the exercise program was also high (6.8± 0.4, maximum score of 7). 5. Mean score for perceived pain was 5.3 ± 1.8, with a maximum score of 7, indicating participants did not perceive an ↑ in pain or discomfort during exercise program.
Sutbeyaz et al. (2005) Turkey Pre-Post N=20	Population: N=20 people with SCI (12 men, 8 women), 14 complete, 6 incomplete (T6-T12), mean age: 31.3yrs; Mean time post injury: 3.8yrs.	1. After training, FVC, FEV1, and vital capacity (VC), were significantly higher than the baseline values. 2. Exercise testing showed ↑ VE_{peak} and PO_{peak} and a

	Intervention: Ventilatory and upper-extremity muscle exercise: 1hr, 3x/wk x 6 wks; Diaphragmatic, pursed lip breathing for 15-min; Air shifting for 5-min; voluntary isocapneic hypernea 10-min; arm-crank exercise. Outcome Measures: Spirometry and peak exercise test.	reduction in the ratio of physiological dead space to tidal volume compared to baseline values.
Hicks et al. (2003) Canada RCT PEDro=5 N=34	Population: Tetraplegia=18, Paraplegia=16; AIS A-D, C4-L1; Age range: 19–65yrs. Intervention: Exercise: 90–120 min/d, 2d/wk, 9 mo. of arm ergometry (15–30 min, ~70% VO_{2peak}) and circuit resistance exercise; Control group: bimonthly education session. Outcome Measures: muscular strength, power output, HR, quality of life ratings.	1. Power output ↑ by 118% and 45% after training in the tetraplegia and paraplegia groups, respectively. 2. There were progressive ↑ in strength over the 9 months of training (range 19%–34%).
Duran et al. (2001) Columbia Pre-Post N=13	Population: thoracic SCI; Mean age: 26.3yrs; Gender: males=12, females=1; Injury severity: complete ASIA A=11, ASIA B=1, ASIA C=1, incomplete=106; Time post-injury= 25mo. Intervention: Patients participated in a 16-wk exercise program, consisting of 3 weekly 120-min sessions. Participants performed mobility, strength, coordination, aerobic resistance, and relaxation activities during the sessions. Outcome Measures: Functional Independence Measure (FIM), arm-crank exercise test, wheelchair skills, maximum strength, anthropometry (body composition measurements), blood lipid levels.	1. Participants showed a significant ↑ in the average FIM score compared to baseline ($p<0.001$); 2. Weight lifted in the bench press exercise (46%, $p<0.0001$), military press (14%, $p<0.0002$), and butterfly press exercise (23%, $p <0.0001$) ↑ significantly from baseline. 3. Number of repetitions for biceps (10%, $p<0.0001$), triceps (18%, $p<0.0001$), shoulder abductors (61%, $p<0.0001$), abdominals (33%, $p<0.009$), and curl back neck exercise (19%, $p<0.0001$) ↑ significantly from baseline. 4. The maximum resistance achieved during the arm

		crank exercise test showed a significant ↑ from baseline (p<0.001), 5. Participants showed a significant ↓ in heart rate 6 minutes after the exercise test from baseline (p<0.05). 6. The time required for the wheelchair skill tests significantly ↓ in all the tasks. 7. No statistically significant changes occurred in body weight, percentage of body fat, lean body weight, cholesterol/high-density lipoprotein cholesterol ratio, or maximum heart rate (p>0.05)
Assorted Approaches to Exercise Training		
Torhaug et al. (2016) Norway Prospective controlled trial N=16	Population: Mean age: 44.3yrs; Gender: male=17, female=0; Level of injury: paraplegia; Level of severity: AIS A=11, AIS B=0, AIS C=1, AID D=4; Mean time since injury: 14.1yrS. Intervention: Participants were allocated to maximal bench press strength training (MST group) or the control group. The MST group trained 3 times per week (4 sets of 4 repetitions at 85-95% bench press 1RM) for 6 wk. The control group performed no formalized exercise routine. Outcome Measures: Work Economy (WE), VO_2 and HR measurements during during wheelchair propulsion at a submaximal workload (50W). Peak measurments were also derived during wheelchair ergometry (WCE) tests.	1. The MST group showed significantly greater improvements in WE. The mean reduction and difference in oxygen consumption between the groups during the submaximal exercise test was -2.6ml/kg/min in favour of the MST group (p=0.007). 2. At 6wks, the mean 1RM force ↑ significantly in the MST group (p=0.001) but no significant changes were seen in the control group. 3. The mean difference of peak power during WCE between groups was significantly improved for the MST group (p=0.001). 4. No significant between or within group differences

		were found for VO_{2peak}, heart rate or body mass.
Lindberg et al. (2012) Sweden Pre-Post N=13	Population: Mean age: 47yrs; Gender: males=8, females=5; Level of injury: T5-L=13; Time post injury: 3-35yrs. Intervention: The intervention consisted of 3 training sessions on a seated double-poling ergometer (SDPE) per week during a 10 wk period for each participant. All training sessions were carried out in small groups coached by an instructor. A training session lasted approximately 50-min and included a warm-up, 4 interval sessions of 6–7 min and a cool-down. The intervals varied between 15 s and 3-min with rests of 15 s to 1-min. Before and after the training period, aerobic and mechanical power was measured during sub-maximal and maximal double-poling exercises on the ergometer. Outcome Measures: VO_{2peak}, ventilation, heart rate (HR), blood lactate and power output (W).	1. VO_{2peak} uptake ↑ significantly from 1.27±0.39 before to 1.56±0.48 L/min after training. The corresponding values for ml/kg/min were significantly ↑ from 18.52±4.79) before to 22.96±6.27 after the training period. 2. There was a significant improvement in ventilation from 65.47±20.32 to 79.00±26.67) L/min. 3. Blood lactate ↑ significantly from 6.71±1.81 to 8.19±2.41 mmol/L. 4. The HRs rates noted during the maximal test were similar before and after training, mean values being 164 (range 133–183) and 167 (range 136–191) beats/min, respectively, and this difference was not significant. 5. Mean power per stroke and peak pole force (mean of left and right) ↑ significantly from 85.62±27.88 before to 98.79±32.54 W after and from 98.44±20.74 to 121.74±29.20 N, respectively. 6. At the sub-maximal workload, significantly lower mean values were observed in ventilation after the training period (before: 20.85±3.85, after: 23.85±5.79 L/min). 7. Blood lactate levels ↓ significantly from 1.41±0.84

		to 1.06±0.49 mmol/L during the sub-maximal workload test. 8. There were no differences between pre- and post-training values in VO_2, power output or in peak pole force at sub-maximal workload.
Ballaz et al. (2008) France RCT PEDro=6 N=17	Population: 17 participants with chronic paralegia (mean age 48±8yrs, range 35-62 yrs), divided into experimental (n = 9) and control (n = 8). Intervention: passive leg-cycling exercise 6 times weekly for 6 weeks Outcome Measures: Red blood cell velocity in the common femoral artery; Velocity index (a measure of peripheral vessel resistance) was measured before and after a 10-min session of passive cycling exercise.	1. Before training, the resting mean blood flow velocity did not differ between groups. 2. In the experimental group, the post-exercise mean blood flow velocity was significantly higher after training. 3. Post exercise velocity index was significantly lower in experimental group after training.
Cooney & Walker (1986) USA Pre-Post N=10	Population: Mean age: 28.8yrs; Gender: males=7; females=3; Injury etiology: traumatic SCI=10; Level of injury: quadriplegia=5, paraplegia=5. Intervention: Individuals trained on an Omnitron unit and performed two exercises – chest press/chest row and shoulder press/lat pull – 3 times/wk for a period of 9 wks divided into three designated stages. This series of exercises was completed in 30-40min. Outcome Measures: VO_{2peak} and PO_{peak} before and after hydraulic resistance training. Participants exercise electrocardiograms (ECGs) were monitored during exercise to	1. VO_{2peak} was significantly ↑ ($p<0.01$). The quadriplegic and paraplegic participants demonstrated a similar training effect. 2. PO_{peak} was significantly ↑ ($p<0.01$). The quadriplegic subjects showed a greater percent improvement by injury level compared to the paraplegic subjects. 3. Mean HR during stage I of the training program was generally below the intensity recommended for cardiovascular training effects. Mean HR remained elevated for 30 min of exercise and within the 60-

	obtain representative heart rate response to each training stage.	90% maximum HR training zone during stage II. HR was elevated rapidly during stage III training.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Behaviour Change Interventions		
Williams et al. (2021) Canada RCT PEDro=6 $N_{initial}$=32 N_{final}=28	Population: *Intervention Group (IG):* Age=45.8±13.6yr; Gender: males=9, females=5; Level of injury: C1-T6=8, Below T6=6; Level of severity: AIS A=7, B-D=1, Not reported=6; Time since injury=14.7±13.9yr. *Control Group (CG):* Age=45.6±10.5yr; Gender: males=8, females=6; Level of injury: C1-T6=9, Below T6=5; Level of severity: AIS A=6, B-D=3, Not reported=5; Time since injury=18.1±10.9yr. Intervention: Participants were randomized to either an an 8-week behavioural physical activity intervention (n=14) or a control group (n=14). Outcome Measures: Resting Left Ventricular (LV) Structure and Function, Posterior Wall Thickness (PWT), Blood pressure, Common Carotid Artery Intima-Media Thickness (CCA-IMT) and Pulse-Wave Velocity (PWV) were assessed with Ultrasound and Tonometry, respectively. VO_{2peak} & PO_{peak} were determined via a cardiopulmonary exercise test on an arm-crank ergometer.	*Resting Cardiovascular Structure and Function* 1. No significant group, time, or interaction effects for LV volumes, hemodynamics, or LV geometry ($p>0.05$ for all), despite significant improvements in VO_{2peak} and PO_{peak} ($p<0.05$). 2. For diastolic measures, only E' ($p=0.008$) and A' ($p=0.025$) were significantly lower at post-intervention in the IG, but not in the CG. 3. No effects for LV twist mechanics, although untwisting velocity was significantly elevated in the IG compared to the CG ($p=0.014$). 4. No significant change in PWT or CCA-IMT at post-intervention or between groups ($p>0.05$). 5. No significant effects for blood pressure. *Sub-Analysis for Level of Injury (LOI)* 1. No significant changes in cardiovascular structure or function detected at post-

		intervention in the high-LOI group, but there were significant ↑ in LV end-diastolic internal diameter (LVID) and reductions to sphericity in the low-LOI PA group at post-intervention (p=0.027 and p=0.049, respectively). 2. No other significant effects in the low- or high-LOI groups for measures of LV mechanics, Doppler velocities, IMT, PWV, or blood pressure. 3. Both high- and low-LOI cohorts had significant group × time interactions for relative VO_{2peak} (p=0.002 and p=0.006, respectively) and PO_{peak} (p=0.01 for both cohorts). 4. ↑ in self-reported total PA (p=0.99) and moderate-to-vigorous PA (p=0.30) were not different between the high- and low-LOI PA cohorts. *Predictors of VO_{2peak}* 1. Only end-diastolic volume (EDV) and ejection fraction (EF) significantly predicted absolute VO_{2peak}(p=0.004). 2. Participant demographics (body mass, age, LOI, sex) were thereafter input to the model, whereby biological sex (p<0.001) and LOI (p=0.001) were the strongest predictors of VO_{2peak} (p<0.001, Model 2), while EDV (p=0.87) and EF (p=0.11) became negligible. 3. With the addition of peak cardiorespiratory measures, HR_{peak} significantly contributed to

		the model (p=0.011) while VE_{peak} did not. 4. The same mixed modelling approach was applied for predictors of relative VO_{2peak} (mL/kg/min). 5. No resting cardiac or vascular variables were significant predictors; however, when demographics were included, LOI appeared to contribute to the model (p=0.062). 6. With the addition of peak cardiorespiratory variables, HR_{peak} and LOI together were predictive of relative VO_{2peak} (p=0.009).
Nooijen et al. (2017) The Netherlands RCT PEDro=6 $N_{Initial}$=45; N_{Final}=39	Population: *Intervention group:* Mean age: 44 yr; Gender: males=17, females=3; Level of injury: Tetraplegia=7, Paraplegia (13); Mean time post-injury: 139 days. *Control group:* Mean age: 44 yr; Gender: males=16, females=3; Level of injury: Tetraplegia=6, Paraplegia=13; Mean time post-injury: 161 days Intervention: *Intervention group:* A behavioural intervention promoting physical activity, involving 13 individual sessions delivered by a lifestyle coach who was trained in motivational interviewing. The intervention began 2 mo. before and ending 6 mo. after discharge from inpatient rehabilitation. *Control group:* Regular rehabilitation Outcome Measures: Physical capacity as determined during a maximal handcycle exercise test, body mass index (BMI), blood pressure, fasting lipid profile,	1. Diastolic blood pressure improved significantly 12 months after discharge (p=0.01), 2. Total cholesterol (p=0.01) and low-density lipoprotein cholesterol (p=0.05) improved significantly 12 months after discharge 3. Participation improved significantly 12 months after discharge (p<0.01). 4. There seemed to be a clinically relevant between-group difference for peak power output, BMI and general health perceptions; however, the differences between the groups were not statistically significant (p>.05).

	social participation (IMPACT-S), 36-item Short Form Health Survey questionnaire (SF-36).	
Ambulation/Stepping Training for Individuals With Motor-Incomplete Injuries		
Lotter et al. (2020) USA RCT Crossover PEDro=6 $N_{Initial}$=17, N_{Final}=15	Population: *Impairment-Based First Group (n=8):* Mean age: 51±17yr; Gender: males=6, females=2; Level of injury: C1-C4=4; C5-C8=2 T1-T10=2; Severity of injury: Incomplete (AIS C or D)=8; Mean time since injury: 3.9±1.8yr; *Task-Specific Frst Group (n=8)*: Mean age: 46±13yr; Gender: males=4, females=4; Level of injury: C1-C4=2; C5-C8=2 T1-T10=4; Severity of injury: Incomplete (AIS C or D)=8; Mean time since injury: 4.3±4.3yr. Intervention: Participants performed either task-specific (upright stepping) or impairment-based training for up to 20 sessions over ≤6wks, with interventions alternated after >4wks delay. Both strategies focused on achieving higher cardiovascular intensities, with training specificity manipulated by practicing only stepping practice in variable contexts or practicing tasks targeting impairments underlying locomotor dysfunction (strengthening, balance tasks, and recumbent stepping). Outcome Measures: Primary outcome measures were fastest speed over short distances and peak treadmill speed. Secondary outcome measures were self-selected speed on the instrumented walkway with instructions to "walk at your normal, comfortable pace," and a six minute walk test with instructions to "cover as much	1. Significantly greater increases in fastest overground and treadmill walking speeds were observed following task-specific versus impairment-based training (p's≤0.01). 2. Gains in balance confidence were observed following task-specific vs. impairment-based training (p=0.02), although incidence of falls was increased with the former protocol (3 vs. 0). 3. A significant time × training interaction was observed for changes in peak recumbent stepping power favoring impairment-based vs task-specific training, (27±45 vs −0.20±33 watts; p=0.04) 4. For secondary metabolic measures, there was a significant main effect of time only for VO_{2peak} during treadmill exercise tests but not for recumbent stepping tests, with no significant interactions.

	ground as possible". Other outcome measures included Berg Balance Scale, 5-times sit-to-stand, Activities-specific Balance Confidence scale, Patient-Reported Outcomes Measurement Information System–Mobility score (version 1.2), lower extremity motor score, VO_{2peak} during graded exercise tests on the treadmill and peak power and VO_{2peak} during a graded recumbent stepping test.	
Wouda et al. (2018) Norway RCT PEDro=7 N=30	Population: Mean age: 41yr; Gender: males=25, females=5; Level of injury:C1-C8, T1-T12, L1-L5, S1-S5; Time since injury: 69 days. Intervention: Participants were randomized into one of the three groups: high-intensity interval training (HIIT) group, moderate-intensity interval training (MIT) group, or a control group (treatment as usual). The HIIT program was 35min, 2x/wk; 10min warm-up at 70% of peak heart rate (HR_{peak}) followed by 4 × 4min intervals at an intensity of 85–95% of HR_{peak} interspersed with 3 × 3 min recovery periods at an intensity of 70% of HR_{peak}. The MIT program consisted of 45min of continous walking or running (depending on their physical ability), 3x/wk at an intensity of 70% of HR_{peak}. Those in control group did not receive any aerobic exercise prescriptions. Outcome Measures: VO_{2peak}, respiratory exchange ratio (RER), HR_{peak}, blood lactate, 6-min walking test (6MWT). Physical activity levels were assessed via	1. VO_{2peak} ↑ from the pre- to post on average 13±17%, 8±13%, and 10±7% in the HIIT, MIT and control groups, respectively. Similarly, the distance walked during the 6MWT ↑ on average by 18±11%, 15±16%, and 9±15%, respectively. There were no statistically significant differences in changes pre- to post-intervention between the groups, after controlling for the pre-test values in either VO_{2peak} (ANCOVA: p=0.94) or 6MWT (p=0.58). 2. Total daily energy expenditure (TDEE) ↑ from the pre- to post-intervention on average 7±11%, 1±15%, and 5±10% in the HIIT, MIT and control groups, respectively. The MIT and control group had a ↓ daily number of steps on average −1±54% and −1±39%, while the HIIT group showed an average ↑ of 16±18%. There was no significant effect of group

	the International Physical Activity Questionnaire (IPAQ).	on the changes in physical activity levels indicated by TDEE (p=0.79) and daily number of steps (p=0.63).
DiPiro et al. (2016) USA Pre-Post $N_{Initial}=10$, $N_{Final}=9$	Population: Mean age: 57.94±9.33 yr; Gender: males=5, females=5; Level of injury: Cervical=9, Thoratic=1; Severity of injury: AIS C=1, AIS D=9; Mean time since injury: 11.1±9.6yr. Intervention: Participants completed voluntary, progressive moderate-to-vigorous intensity exercise on a recumbent stepper (3d/wk for 6wks). Outcome Measures: Primary outcome measures: Aerobic capacity (VO_{2peak}) and self-selected overground walking speed (OGWS). Secondary Outcome Measures: walking economy, 6-minute walk test, daily step counts, Walking Index for Spinal Cord Injury, Dynamic Gait Index and Berg Balance Scale.	1. Aerobic capacity improved significantly from pre- to post-intervention (p=0.011) 2. OGWS improved significantly from pre- to post-intervention (p=0.023). 3. The percentage of VO_{2peak} used while walking at self-selected speed improved significantly from pre- to post-intervention (p=0.03). 4. Daily step counts improved significantly from pre- to post-intervention (p=0.025).
General Sport Training Interventions		
Sarro et al. (2016) Brazil Pre-Post $N_{Initial}=10$, $N_{Final}=7$	Population: Mean age: 26.86±5.87yr; Gender: males=10, females=0; Level of injury: C1-T1=10, T2-L5=0; Mean time since injury: 90.86±55.80mo. Intervention: Regular wheelchair rugby training, consisting of 3-4 session/wk for 2hr/session. Training load was according to the competition schedule, following the traditional annual model divided in preparatory, competition and transition period. Training lasted 1yr. Outcome Measures: Lung volume and tridimensional mobility of four-chest wall	1. During quiet breathing, significant differences were found for tidal volume (p=0.04), superior thorax (p=0.04) and inferior thorax (p=0.01) mobility, representing ↑ of 16.9%, 61.3% and 83.7%, respectively. 2. During maximal breathing, significant differences and large effect sizes were found for vital capacity (p=0.01) and superior thorax (p=0.04) mobility, representing ↑ of 24.8 and 31.5%, respectively.

	compartments (superior and inferior thorax, superior and inferior abdomen).	
Matos-Souza et al. (2016) Brazil Prospective Observational N=17	Population: *Sports Group (n=8);* Mean Age=28.3±2.5yr; Gender: Males=8, Females=0; Level of Injury: C5-T9; Severity of Injury: AIS A=7, B=1; Mean Time Since Injury=5.1±1.3yr. *Control Group (No Sports; n=9);* Mean Age=33.7±2.2yr; Gender: Males=9, Females=0; Level of Injury: C4-T8; Severity of Injury: AIS A=8, B=1; Mean Time Since Injury=7.6±1.5yr. Intervention: Not applicable. Prospective observational study to determine whether involvement in adapted sports is associated with long-term changes in carotid atherosclerosis in individuals with SCI. Outcome measures were assessed at baseline and 5yr follow-up. Outcome Measures: Cholesterol, triglycerides, c-reactive protein, blood pressure, heart rate, stroke volume, cardiac output, peripheral vascular resistance, carotid ultrasonography.	1. At follow-up the control group experienced: significant ↑ in resting heart rate (p=0.004) and no significant changes in carotid intima-media thickness or diameter (p>0.05). 2. At follow-up the sports group experienced: significant ↓ in carotid intima-media thickness (p=0.001) and diameter (p<0.001). No other variables were significantly different at follow-up.
Moreno et al. (2013) Brazil Pre-Post and cross-sectional comparison N=15	Population: N=15 male tetraplegic individuals with SCI divided into a control (n=7) and rugby player (n=8) group. Control group: mean±SD age: 33±9yr; DOI: 73±53 months. Rugby player group: mean±SD age: 26± 6 yr; DOI: 87±52 months. Intervention: Experimental group participated in a regular 1-	1. There was a significant ↑ in all variables after training: (mean±SD) FVC ↑ from 2.7±0.9 L to 3.0±1.0 L. 2. FEV1 ↑ from 2.5±0.9 to 2.8±1.0 L. 3. MVV ↑ from 107±28 to 114±24 L/min. 4. No significant difference between the control group

	year wheelchair rugby training program that involved stretching, strength exercises, and cardiovascular resistance training (2-hour sessions, 3-4x per week). The control participants were only assessed once at baseline. Outcome Measures: forced vital capacity (FVC), forced expiratory volume measured during the first phase (FEV1) and maximal voluntary ventilation (MVV).	and rugby players regarding spirometric variables, except for MVV, which was higher in rugby players.
Fukuoka et al. (2006) Japan Pre-Post N=8	Population: N=8 (7M 1F); mean±SD age: 46.5±8.3yrs; AIS B; T7-L1. Intervention: Wheelchair training program: 30 min at 50% HRR, 3x/wk, for 60 days. Outcomes were assessed before training, after 7, 15, 30 and 60 days of training Outcome Measures: VO_{2peak}, HR.	1. Mean VO_{2peak} ↑ with training, became significant from 30th training day onwards (baseline = 17 ml/kg/min vs. T30 = 18 ml/kg/min). 2. Steady state HR assessed during the constant workload test (50% of $VO_{2peak)}$ ↓ significantly by the 7th training day and plateau from day 15 onwards (baseline HR = 123 ±11 bpm, day 7 = 112±11 bpm, day 15 = 109±6 bpm).
General Rehabilitation		
Nooijen et al. (2012) Netherlands Observational N=30	Population: Mean age: 42yr; Gender: 72% males; Injury: 53% tetraplegia, 72% motor-complete SCI; Mean time of inpatient rehabilitation: 7mo. Intervention: Outcomes were assessed at 4 timpeoints : start of active rehabilitation (t1), 3 months later (t2), at discharge from inpatient rehabilitation (t3), and 1 year after discharge (t4) Outcome Measures: VO_{2peak}, PO_{peak}, Isometric muscle strength, Lipid profile	1. After correcting for confounding variables, physical activity level was significantly correlated to VO_{2peak} and PO_{peak} ($p<0.01$). An ↑ in physical activity level was associated with an ↑ in aerobic capacity. 2. With regard to lipid profile, an ↑ in activity level was correlated to a ↓ in concentration of TG ($P<0.01$) and to a ↓ in TC/HDL ratio ($P<0.05$).

	(cholesterol, triglycerides) and physical activity level (assessed via an accelerometery-based activity monitor).	3. Corrected for confounders and time, an ↑ in physical activity level of 26 min day was associated with an ↑ in 0.11 L min (ß=0.059*1.79%) in VO_{2peak}. The same ↑ of 26 min day, corrected for confounders and time, was associated with an ↑ in PO_{peak} of 4.06W (ß=2.27*1.79%), a ↓ in TG of 0.14 mmol (ß=0.076*1.79%) and a ↓ in TC/HDL ratio of 0.23 (ß=0.127*1.79%).
Valent et al. (2008) The Netherlands Observational N=137	Population: SCI participants: C5 or lower; aged 18-65yrs. *Hand cycling group:* 35 participants with paraplegia, 20 with tetraplegia. *Non-hand cycling group:* 56 with paraplegia, 26 with tetraplegia. Intervention: All participants followed the usual care rehabilitation program in their own rehabilitation centres, with or without regular hand cycling exercise. Study included three measurements: 1) when participants could sit in a wheelchair for three hours; 2) on discharge; 3) 1 year after discharge. Outcome Measures: VO_{2peak}; FVC; peak expiratory flow rate (PEFR).	1. Significant ↑ (26% in hand cycling group vs. 8% non-hand cycling group) in VO_{2peak} in paraplegic patients, whereas tetraplegic patients showed no change. 2. No change in pulmonary function (FVC or PEFR) found in either participants with paraplegia or tetraplegia.
Grange et al. (2002) France Pre-Post N=14 (SCI=7)	Population: *Able-bodied (n=7):* Mean age: 26.6yr; Gender: males=7. *SCI (n=7):* Mean age: 35.2yrs; Mean time since injury: 12.3yrs; Gender: males=7; Level of injury: paraplegia; Level of severity: AIS A. Intervention: All individuals participated in a rehabilitation program composed of 3 sessions/wk for 6wk. Each	1. There was no significant difference in both groups for PE between the two GXT (p>0.05). However, a significant ↓ in the PE values (p<0.01) was observed in both groups during the SWEET 2. 2. There was no significant difference in HR_{max} between the two GXT, but

	session consisted of a 45 min Square Wave Exercise Tests (SWEET). During each work bout, a 4 min period of moderate work (base level) was followed by a 1 min period of heavy work (Peak level). The maximal graded exercise tests (GXT) and the SWEET were performed before (GXT 1 and SWEET 1) and after a 6 wk training period (GXT 2 and SWEET 2). Outcome Measures: VO_{2peak}, maximal tolerated power (MTP), heart rate and perceived exertion (PE).	a significant ↓ in HR ($p<0.0001$ for baseline HR and $p<0.001$ for HR_{peak}) was observed in SWEET 2 compared to SWEET 1. 3. The MTP and VO_{2peak} ↑ significantly in able-bodied ($p<0.0001$) and paraplegic groups ($p<0.05$).
Multi-Modal Training		
Betancourt et al. (2020) USA Case-Control N=32	Population: *SCI Group (n=16):* Mean age: 30yrs; Gender: males=12, females=4; Level of injury: T1-T2 paraplegia=16; Mean time since injury: 12yrs. *Able-bodied Group (n=16):* Mean age: 29yrs; Gender: males=12, females=4. Intervention: Individuals took part in a 45-minute upper-extremity circuit training protocol which consisted of three ‘circuits’ of 3 pairs of isoinertial resistance exercise interspersed with two minutes of high-cadence, low-resistance arm-crank ergometry. Outcome Measures: Median nerve ultrasound evaluation at the pisiform and radius pre and post-upper extremity exercise. Ultrasound parameters included cross-sectional area (CSA), and gray scale (GS).	1. No statistical differences in median nerve response to exercise in SCI and controls. 2. At pisiform, cross-sectional areas were inversely associated with pre-exercise values. 3. Participants with pre-exercise cross sectional area values ^{3}10.00mm at the pisiform responded to exercise with ↓ in cross sectional areas and gray scale. 4. Participants with pre-exercise cross sectional areas ^{3}9.99mm at the pisiform responded to exercise with no change in cross-sectional areas and ↑ gray scale.
Kim et al. (2019) Korea	Population: Mean Age=36.8±6.9yrs; Gender:	1. Compared to usual care, the exercise program

RCT PEDro=6 $N_{Initial}$=19, N_{Final}=17	Males=11, Females=6; Level of Injury: L1-C4; Severity of Injury: AIS A=9, B=7, C=1; Time Since Injury ≥1yr. Intervention: Participants were randomized to complete a combined exercise program consisting of aerobic and resistance exercises (60 min/d, 3 d/wk for 6 wk) or usual care. The exercise program consisted of the following: 25-min warm-up consisting of 5-min of joint exercises, 15-min of exercise on an arm-crank ergometer, and 5-min of stretching, followed by a 30-min exercise program (resistance training circuit and aerobic training), and a 5-min of cooldown (stretching). Circuit and aerobic exercise was performed at a moderate-to-vigorous intensity (4-8 on a Borg CR10 scale). Outcome measures were assessed at baseline and 6 wk. Outcome Measures: VO_{2peak}, body mass index, percent body fat, waist circumference, shoulder abduction /adduction, shoulder flexion/extension, elbow flexion/extension, fasting insulin levels and homeostasis model assessment of insulin resistance (HOMA-IR) levels.	significantly: ↓ the mean fasting insulin, ↓ HOMA-IR, ↑ HDL cholesterol, ↓ waist circumference, and ↑ muscle strength of the shoulder flexors, extensors, adductors, abductors, and elbow flexors (group × time interactions P<0.05). 2. There were no significant (group × time interactions (p>0.05) on measures of: VO_{2peak}, lean mass, body fat percentage, total cholesterol and LDL cholesterol.
Yarar-Fisher et al. (2018) USA RCT PEDro=5 $N_{Initial}$=20, N_{Final}=11	Population: Mean age: 46.0±7.8yrs; Gender: males=10, females=1; Level of injury: C1-T1=4, T2-L5=7; Level of severity: AIS A=3, AIS B=8; Mean time since injury: 21.8±6.3yrs. Intervention: Isocaloric high-protein (HP) diet vs. a multi-modal exercise intervention, which consisted of upper-body resistance training (RT) in	1. VO_{2peak} significantly (P<0.05) ↑ from 13.2±3.4 to 14.6±3.3 ml/kg/min. 2. Upper-body strength (arm-curl, overhead press, chest fly and lat pull down) significantly (P<0.05) ↑.

	addition to neuromuscular electrical stimulation (NMES)-induced-RT for paralytic Vastus Lateralis muscle. Strength training was combined with high-intensity arm-crank exercises for improving cardiovascular endurance. Exercise training was completed 3 days/wk for 8 wk. Outcome Measures: Dual-energy X-ray absorptiometry scan, VO_{2peak}, and maximum voluntary upper-body strength.	
Gant et al. (2018) USA Pre-Post N=8	Population: Mean age=31.4yrs; Gender: males=6, females=2; Time since injury: 10.5yrs; Level of injury: T2 - T10; Severity of injury: AISA A=4, B=4. Intervention: Participants underwent three, 4-wk long multi-modal exercise conditioning and rehabilitation interventions, each separated by a one wk period of multiple body systems assessments. Each participant was in the trial for 19 continuous weeks. Outcome measurements were assessed after screening for two baseline assessments and at 4, 9, 14 and 19 wk. Outcome Measures: Neurological motor and sensory impairment; Upper-extremity muscle strength; VO_{2peak}; Blood pressure; cholesterol, lipids and biomarkers of glycemic control and inflammation; Clinical and electrophysiological spasticity measures; Pain history and pain-related sensory function; Self-reported function; Patient-reported global impression of change.	1. No significant differences in neurological motor and sensory impairment, blood pressure, cholesterol, lipids, biomarkers of glycemic control and inflammation, as well as chronic pain were observed ($p>0.05$). 2. Upper-extremity muscle strength significantly improved from baseline ($p=0.001$). 3. VO_{2peak} was not significantly different from baseline ($p>0.05$). 4. Two participants experienced clinically significant improvements in self-reported function ($p<0.05$). All participants reported a perceived improvement.

Pelletier et al. (2015) Canada RCT PEDro=4 N=23	Population: Mean age: 40.4yrs; Gender: males=21, females=2; Level of injury: C1-T11=23; Time post injury: 12.0yrs. Intervention: Participants were randomized to receive SCI-specific physical activity guidelines (PAG) for improving fitness or active control (CON). PAG training was 2x/wk for 16wks and involved 20-min of aerobic exercise at a moderate-to-vigorous intensity (RPE 3–6 on 10-point scale) and three sets of 10 repetitions (at 50–70% 1 repetition maximum). Participants in the CON group were members in a twice weekly community exercise program geared for adults with SCI. Outcome Measures: VO_{2peak}, Central and peripheral RPE (Borg 10- point scale), Heart rate (HR), Satisfaction with the guidelines and strength.	1. There was a significant group × time interaction for relative (p=0.01) and absolute (p=0.004) VO_{2peak}, indicating ↑ aerobic capacity in the PAG group following training. While there was a 13.4% ↑ in PO_{peak} in the PAG group following training, it did not reach statistical significance (p=0.059) 2. Post training, the PAG group completed a submaximal exercise test at a higher power output than the CON group (p=0.01). 3. There was a significant group × time interaction for vertical bench press (p=0.02), seated row (p=0.03) and elbow extension (p<0.01), reflective of mean strength ↑ in the PAG group of 7.3 ± 6.4 kg, 8.3 ± 6.1 kg and 22.5 ± 23.1 kg, respectively. 4. Satisfaction with both the aerobic (6.3± 0.64) and resistance (6.7± 0.5) aspects of the PAG training protocol were high (maximum score of 7). Enjoyment of the exercise program was also high (6.8± 0.4, maximum score of 7). 5. Mean score for perceived pain was 5.3 ± 1.8, with a maximum score of 7, indicating participants did not perceive an ↑ in pain or discomfort during exercise program.

Sutbeyaz et al. (2005) Turkey Pre-Post N=20	Population: N=20 people with SCI (12 men, 8 women), 14 complete, 6 incomplete (T6-T12), mean age: 31.3yrs; Mean time post injury: 3.8yrs. Intervention: Ventilatory and upper-extremity muscle exercise: 1hr, 3x/wk x 6 wks; Diaphragmatic, pursed lip breathing for 15-min; Air shifting for 5-min; voluntary isocapneic hypernea 10-min; arm-crank exercise. Outcome Measures: Spirometry and peak exercise test.	1. After training, FVC, FEV1, and vital capacity (VC), were significantly higher than the baseline values. 2. Exercise testing showed ↑ VE_{peak} and PO_{peak} and a reduction in the ratio of physiological dead space to tidal volume compared to baseline values.
Hicks et al. (2003) Canada RCT PEDro=5 N=34	Population: Tetraplegia=18, Paraplegia=16; AIS A-D, C4-L1; Age range: 19–65yrs. Intervention: Exercise: 90–120 min/d, 2d/wk, 9 mo. of arm ergometry (15–30 min, ~70% VO_{2peak}) and circuit resistance exercise; Control group: bimonthly education session. Outcome Measures: muscular strength, power output, HR, quality of life ratings.	1. Power output ↑ by 118% and 45% after training in the tetraplegia and paraplegia groups, respectively. 2. There were progressive ↑ in strength over the 9 months of training (range 19%–34%).
Duran et al. (2001) Columbia Pre-Post N=13	Population: thoracic SCI; Mean age: 26.3yrs; Gender: males=12, females=1; Injury severity: complete ASIA A=11, ASIA B=1, ASIA C=1, incomplete=106; Time post-injury= 25mo. Intervention: Patients participated in a 16-wk exercise program, consisting of 3 weekly 120-min sessions. Participants performed mobility, strength, coordination, aerobic resistance, and relaxation activities during the sessions. Outcome Measures: Functional Independence Measure (FIM), arm-crank exercise test,	1. Participants showed a significant ↑ in the average FIM score compared to baseline ($p<0.001$); 2. Weight lifted in the bench press exercise (46%, $p<0.0001$), military press (14%, $p<0.0002$), and butterfly press exercise (23%, $p<0.0001$) ↑ significantly from baseline. 3. Number of repetitions for biceps (10%, $p<0.0001$), triceps (18%, $p<0.0001$), shoulder abductors (61%, $p<0.0001$), abdominals (33%, $p<0.009$), and curl

	wheelchair skills, maximum strength, anthropometry (body composition measurements), blood lipid levels.	back neck exercise (19%, p<0.0001) ↑ significantly from baseline. 4. The maximum resistance achieved during the arm crank exercise test showed a significant ↑ from baseline (p<0.001), 5. Participants showed a significant ↓ in heart rate 6 minutes after the exercise test from baseline (p<0.05). 6. The time required for the wheelchair skill tests significantly ↓ in all the tasks. 7. No statistically significant changes occurred in body weight, percentage of body fat, lean body weight, cholesterol/high-density lipoprotein cholesterol ratio, or maximum heart rate (p>0.05)
Totosy de Zepetnek et al. (2015) Canada RCT PEDro=4 $N_{initial}$=23 N_{final}=17	Population: *SCI-specific Physical Activity Guidelines (PAG) for improving fitness:* Age=39±11yr.; Gender: males=12, females=0; Level of injury: C3-T10; Level of severity: AIS A-B=3, C-D=9; Time since injury=15±10yr. *Control Group* Age=42±13yr.; Gender: males=9, females=2; Level of injury: C1-C11; Level of severity: AIS A-B=5, C-D=6; Time since injury=9±10yr. Intervention: Participants were randomized to receive SCI-specific physical activity guidelines (PAG) for improving fitness or active control (CON). PAG training was 2x/wk for 16wk and involved 20min of aerobic exercise at a moderate-to-	*Traditional CVD Risk Factors and Blood Biomarkers:* 1. No change in HbA1c, lipids, fasting insulin, adipokines, proinflammatory markers, and thrombotic markers in either group. *2. Body Composition* 3. There was a group × time interaction for WBM (p=0.03), WBF (p=0.04), and VAT (p=0.04). 4. Trend toward an interaction for LF (p=0.056). 5. Group × time interaction for WC (p=0.03) and BMI (p=0.02). 6. No changes observed in WBL mass.

	vigorous intensity (RPE 3–6 on 10-point scale) and three sets of 10 repetitions (at 50–70% 1 repetition maximum). The control group maintained existing physical activity levels with no guidance on training intensity Outcome Measures: Blood biomarkers; glycosylated hemoglobin (HbA1c), lipids (triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, total cholesterol/high-density lipoprotein cholesterol), fasting insulin, adipokines (leptin, adiponectin), proinflammatory markers (IL-6, TNF-α), and prothrombotic markers (PAI-1), Body composition;whole body mass (WBM), leg fat (LF), body mass index (BMI), waist circumference (WC), whole-body fat (WBF), whole-body lean (WBL), and visceral adipose tissue (VAT), Arterial structure and function; Heart rate (HR) and blood pressure (BP) were monitored continuously, Carotid pulse pressure (CPP), carotid distensibility (CD), intima media thickness (IMT), lumen diameter (LD), and wall-to-lumen ratio (WLR), central and peripheral (arm, leg) pulse wave velocity (PWV), brachial (BA) and superficial femoral artery (SFA) endothelial-dependent (flow-mediated dilation [FMD]) and endothelial-independent (NTG) vasodilation.	*Arterial Structure and Function* 1. Group × time interaction was found for CD (p=0.05). 2. No interactions were found for other measures of carotid artery structure (CPP, IMT, WLR), indices of regional stiffness (central, arm, leg PWV), or vascular function (BA, SFA, endothelial dependent [FMD] or independent [NTG] vasodilation).
Assorted Approaches to Exercise Training		
Torhaug et al. (2016)	Population: Mean age: 44.3yrS; Gender: male=17, female=0; Level	1. The MST group showed significantly greater

Norway Prospective controlled trial N=16	of injury: paraplegia; Level of severity: AIS A=11, AIS B=0, AIS C=1, AID D=4; Mean time since injury: 14.1yrS. Intervention: Participants were allocated to maximal bench press strength training (MST group) or the control group. The MST group trained 3 times per week (4 sets of 4 repetitions at 85-95% bench press 1RM) for 6 wk. The control group performed no formalized exercise routine. Outcome Measures: Work Economy (WE), VO_2 and HR measurements during during wheelchair propulsion at a submaximal workload (50W). Peak measurments were also derived during wheelchair ergometry (WCE) tests.	improvements in WE. The mean reduction and difference in oxygen consumption between the groups during the submaximal exercise test was -2.6ml/kg/min in favour of the MST group (p=0.007). 2. At 6wks, the mean 1RM force ↑ significantly in the MST group (p=0.001) but no significant changes were seen in the control group. 3. The mean difference of peak power during WCE between groups was significantly improved for the MST group (p=0.001). 4. No significant between or within group differences were found for VO_{2peak}, heart rate or body mass.
Lindberg et al. (2012) Sweden Pre-Post N=13	Population: Mean age: 47yrs; Gender: males=8, females=5; Level of injury: T5-L=13; Time post injury: 3-35yrs. Intervention: The intervention consisted of 3 training sessions on a seated double-poling ergometer (SDPE) per week during a 10 wk period for each participant. All training sessions were carried out in small groups coached by an instructor. A training session lasted approximately 50-min and included a warm-up, 4 interval sessions of 6–7min and a cool-down. The intervals varied between 15 s and 3-min with rests of 15 s to 1-min. Before and after the training period, aerobic and mechanical power was measured during sub-maximal	1. VO_{2peak} uptake ↑ significantly from 1.27±0.39 before to 1.56±0.48 L/min after training. The corresponding values for ml/kg/min were significantly ↑ from 18.52±4.79) before to 22.96±6.27 after the training period. 2. There was a significant improvement in ventilation from 65.47±20.32 to 79.00±26.67) L/min. 3. Blood lactate ↑ significantly from 6.71±1.81 to 8.19±2.41 mmol/L. 4. The HRs rates noted during the maximal test were similar before and after training, mean values being 164 (range 133–183) and 167 (range 136–191)

	and maximal double-poling exercises on the ergometer. Outcome Measures: VO$_{2peak}$, ventilation, heart rate (HR), blood lactate and power output (W).	beats/min, respectively, and this difference was not significant. 5. Mean power per stroke and peak pole force (mean of left and right) ↑ significantly from 85.62±27.88 before to 98.79±32.54 W after and from 98.44±20.74 to 121.74±29.20 N, respectively. 6. At the sub-maximal workload, significantly lower mean values were observed in ventilation after the training period (before: 20.85±3.85, after: 23.85±5.79 L/min). 7. Blood lactate levels ↓ significantly from 1.41±0.84 to 1.06±0.49 mmol/L during the sub-maximal workload test. 8. There were no differences between pre- and post-training values in VO$_2$, power output or in $_{peak}$ pole force at sub-maximal workload.
Ballaz et al. (2008) France RCT PEDro=6 N=17	Population: 17 participants with chronic paralegia (mean age 48±8yrs, range 35-62 yrs), divided into experimental (n = 9) and control (n = 8). Intervention: passive leg-cycling exercise 6 times weekly for 6 weeks Outcome Measures: Red blood cell velocity in the common femoral artery; Velocity index (a measure of peripheral vessel resistance) was measured before and after a 10-min session of passive cycling exercise.	1. Before training, the resting mean blood flow velocity did not differ between groups. 2. In the experimental group, the post-exercise mean blood flow velocity was significantly higher after training. 3. Post exercise velocity index was significantly lower in experimental group after training.

Cooney & Walker (1986) USA Pre-Post N=10	Population: Mean age: 28.8yrs; Gender: males=7; females=3; Injury etiology: traumatic SCI=10; Level of injury: quadriplegia=5, paraplegia=5. Intervention: Individuals trained on an Omnitron unit and performed two exercises – chest press/chest row and shoulder press/lat pull – 3 times/wk for a period of 9 wks divided into three designated stages. This series of exercises was completed in 30-40min. Outcome Measures: VO$_{2peak}$ and PO$_{peak}$ before and after hydraulic resistance training. Participants exercise electrocardiograms (ECGs) were monitored during exercise to obtain representative heart rate response to each training stage.	1. VO$_{2peak}$ was significantly ↑ ($p<0.01$). The quadriplegic and paraplegic participants demonstrated a similar training effect. 2. PO$_{peak}$ was significantly ↑ ($p<0.01$). The quadriplegic subjects showed a greater percent improvement by injury level compared to the paraplegic subjects. 3. Mean HR during stage I of the training program was generally below the intensity recommended for cardiovascular training effects. Mean HR remained elevated for 30 min of exercise and within the 60-90% maximum HR training zone during stage II. HR was elevated rapidly during stage III training.

Discussion

Twenty-three studies in total have investigated the effect of other physical activity interventions on cardiorespiratory fitness, pulmonary function or cardiovascular health outcomes. Despite the wide variability of these other physical activity interventions, the following classifications have been used to group studies: 1. Behaviour change interventions (n=2), 2. Ambulation/stepping training for individuals with motor-incomplete injuries (n=3), 3. Sport-related training interventions (n=4), 4. General rehabilitation (n=3), 5. Multi-modal interventions (n=7) and 6. Assorted approaches to exercise training (n=4).

There is mixed evidence as to whether behaviour change interventions can improve cardiorespiratory fitness or cardiovascular health outcomes in this population, which maybe dependent on time since injury. One higher RCT (PEDro scores ≥6) in individuals with chronic (>1-year) SCI showed a significant improvement in aerobic capacity but no significant improvements in cardiac indices or hemodynamics (Williams et al. 2021). The authors note different responses between participants stratified by level of injury as part of a sub-group analysis, which warrants further investigation. The second higher RCT, in the sub-acute setting post-SCI, indicated clinically relevant between group differences for peak power output, although the differences between groups were not statistically significant (also the case for VO_{2peak}) (Nooijen et al. 2017). However, a significant intervention effect was observed for diastolic blood pressure.

The evidence regarding whether ambulation training improves cardiorespiratory fitness for individuals with motor-incomplete injuries is currently unclear. One higher level RCT (Wouda et al. 2018) indicated no statistically significant (P = 0.94) differences in the pre-post changes between HIIT, MIT or control group following 12 weeks of continuous running or walking. One randomized cross-over study (Lotter et al. 2020) revealed a significant time effect (irrespective of task-specific vs. impairment-based training) for treadmill VO_{2peak} but not recumbent stepping VO_{2peak} and a pre-post intervention indicated that 6 weeks of ambulation type exercise can improve VO_{2peak} (2016). Further research is required to support the efficacy of ambulation training to improve cardiorespiratory fitness, pulmonary function or cardiovascular health outcomes in individuals with motor-incomplete SCI.

With regards to the general sport training studies, two studies investigated wheelchair rugby, one study a general level of sport conditioning and another study a general wheelchair propulsion training program. There were no RCTs for this category of studies (3 pre-post interventions and 1 prospective observational study), which ultimately limits the strength of the evidence. This is also the case for the three general rehabilitation studies (2 observational studies and 1 pre-post intervention), which predominantly included participants with sub-acute injuries.

With regards to multi-modal exercise interventions, a variety of approaches have been tested in the literature, with interventions combining strength training, aerobic exercise and functional electrical stimulation (to activate sublesional muscles) as part of a combined exercise program. While three lower RCTs (PEDro score < 6) indicated an improvement in aerobic capacity, the only higher RCT (Kim et al. 2019) demonstrated no significant improvement relative to the control group. An additional pre-post study indicated significant improvements in peak power with multi-modal training, however, this was with 16 weeks of exercise consisting of 3 weekly 120-minute sessions.

There is a wide degree of variability in the exercise modalities adopted for the assorted approaches to exercise training category, including: simulated wheelchair rolling exercise, passive leg-cycling, seated double-poling ergometry and strength exercises. Therefore, it is difficult to provide generalisable recommendations for this category.

Conclusion

There is moderate evidence (Level 1b) that behaviour change interventions can improve cardiorespiratory fitness in individuals with chronic (>1 year) SCI (Williams et al. 2021). However, there is conflicting evidence around the benefits of behaviour change interventions that are delivered in the sub-acute setting post-SCI (Nooijen et al. 2017). Further research is necessary in the sub-acute setting to inform conclusions around the efficacy of behaviour change interventions for individuals in the early stages post-injury.

There is moderate evidence (Level 2) that multi-modal training approaches, 2-3 times per week for ≥8 weeks improve cardiorespiratory fitness in individuals with SCI (Pelletier et al. 2015; Yarar-Fisher et al. 2018). It should be noted that the length of intervention may be important as a higher RCT revealed no significant improvements in cardiorespiratory fitness following only 6 weeks of mutli-modal training (Kim et al. 2019).

There is Level 2 evidence (Totosy de Zepetnek et al. 2015) that multi-modal training improves carotid distensibility.

Weak evidence (Level 3/4) (Cooney & Walker, 1986; Lindberg et al. 2012) provides early support for the efficacy of assorted approaches to exercise training but more research is needed to draw firm conclusions. However, there is moderate evidence (Level 1b) (Ballaz et al. 2008) that passive leg-cycling (performed frequently, 6 times per week for 6 weeks) may improve post-exercise blood flow velocity in the common femoral artery.

There is conflicting evidence regarding the efficacy of ambulation training to improve cardiorespiratory fitness in individuals with SCI. While Level 4 evidence (pre-post and randomised cross-over studies) may indicate early support for this exercise intervention (DiPiro et al. 2016; Lotter et al. 2020), a higher RCT indicated no significant improvements in cardiorespiratory fitness (Wouda et al. 2018). More research is needed to draw conclusions.

There is only weak evidence (Level 4) (Fukuoka et al. 2006; Matos-Souza et al. 2016; Moreno et al. 2013; Sarro et al. 2016) that sport training interventions and general rehabilitation programs can improve cardiorespiratory fitness, pulmonary function or cardiovascular health outcomes. Further research is needed to indicate the most effective sport training programs and rehabilitation methods in this population.

3.2 Orthostatic Hypotension

Orthostatic hypotension is a condition characterized by a reduction in in systolic blood pressure of at least 20mmHg (or a reduction in diastolic blood pressure of at least 10mmHg) in response to a change in body position from supine (lying) to upright (seated or standing) ("Consensus statement on the definition of orthostatic hypotension, pure autonomic failure, and multiple system atrophy. The Consensus Committee of the American Autonomic Society and the American Academy of Neurology" 1996). Orthostatic hypotension typically affects individuals with cervical or high-thoracic SCI who lack the ability to vasconstrict the vascular beds in the abdomen due to the loss of supraspinal sympathetic control (Teasell et al. 2000). The presence of orthostatic hypotension can have a significant burden of morbidity as it impairs activities of daily living and can be associated with feelings of tiredness as well as reduced cognition and cerebral perfusion(Sahota et al. 2012). In addition to altered neural control following SCI a number of other risk factors can precipitate an increased risk for OH including low blood volume, low sodium levels, and deconditioning of the heart and blood vessels (Claydon & Krassioukov, 2006). Within those with cervical SCI, it is reported that up to 82% suffer from orthostatic hypotension (Illman et al. 2000).

Orthostatic hypotension is traditionally managed pharmacologically using medications similar to that in the general population, despite no SCI-specific validation. Of the drugs most commonly used Midodrine has most evidence supporting efficacy in the SCI population. Despite relatively widespread use there are side-effects including potential urinary bladder dysreflexia. As such, a number of non-pharmacological avenues are being explored to manage OH in people with SCI, including pressure stockings, abdominal bindings and various forms of exercise, the latter of which is reviewed below.

The majority of studies that have investigated the efficacy of exercise to abrogate the severity of orthostatic hypotension have conducted an acute study in which an individual with SCI is either tilted into the upright position, moved from supine to standing, or encased within a lower-body negative pressure (LBNP) chamber. Both the tilt-test and the LBNP chamber simulate the blood pressure change associated with orthostasis. In response to these acute hemodynamic challenges, investigators have subsequently demonstrated that stimulation of the lower-limbs with either functional electrical stimulation exercise or neuromuscular stimulation improves blood pressure control and/or central hemodynamics.

Table 7. Effect of Physical Activity Orthostatic Hypotension

Author Year; Country Score Research Design Total Sample Size	Methods	Outcome
Ditor et al. (2005) Canada Pre-Post N=8	Population: Sensory incomplete (AIS B-C) cervical SCI (C4-C5). Intervention: 6 months of body weight-supported treadmill training (BWSTT). Outcomes Measures: HR, BP, and orthostatic responses, heart-rate variability.	1. Resting HR was reduced but no change in resting BP after BWSTT. 2. BWSTT did not improve BP or HR during head-up tilt (HUT).
Otsuka et al. (2008) Japan Prospective controlled trial N=30	Population: 10 men with tetraplegia, age: 29±6 years who were on a wheelchair basketball team and had physical training for at least 2hr/day, 2 days/week, for 2 years; 10 untrained men with tetraplegia, age 32±6 years and 10 able-bodied sedentary men, age 23±2 years were included as controls. Treatment: regular physical activity training Outcome Measures: HR, BP; electrocardiogram; autonomic nervous system activity in supine and 60° sitting position.	1. During supine rest, trained subjects with tetraplegia had significantly lower HR than the able-bodied controls. 2. Increase in HR from supine to sitting position in trained and untrained subjects with tetraplegia. 3. Untrained subjects with tetraplegia, but not trained subjects with tetraplegia demonstrated significant orthostatic responses (increased sympathetic activity and reduced vagal activity).

Discussion

There is insufficient evidence in the literature to determine whether chronic exposure to exercise training improves orthostatic intolerance in those with cervical SCI. Indeed, only a single study has compared the severity of orthostatic tolerance between highly-trained and untrained individuals with cervical SCI. This study demonstrated that there is level 5 evidence that individuals with SCI who are highly trained (i.e., competitive athletes) have better cardiovascular stability (i.e., less changes in the spectral components of heart rate and blood pressure during an orthostatic challenge) than those who are untrained.

There is insufficient evidence in the literature to determine whether a BWSTT intervention improves orthostatic intolerance in those with cervical SCI. Indeed, only a single study has compared the severity of orthostatic tolerance pre- and post-BWSTT. This study demonstrated that there is no improvement in the severity of orthostatic intolerance in individuals with cervical SCI who underwent BWSTT.

Conclusion

There is level 4 evidence (Ditor et al. 2005) from 1 study that 6 months of BWSTT does not reduce (or worsen) the severity of orthostatic intolerance in individuals with incomplete cervical SCI.

There is level 5 evidence (Otsuka et al. 2008) that chronic exposure to athletic training (at least 2hr/wk) improves cardiovascular stability during an orthostatic challenge in individuals with cervical SCI.

3.2 Metabolic Health

Metabolic health is a broad term referring to the transportation, use, and storage of energy via the building up (anabolic) or breaking down (catabolic) of chemicals in the body. Transport of new (e.g. dietary) and existing (e.g., stored) fuels occurs via complex trafficking of molecular cargo via blood and lymph vessels between different organ systems. Use, or expenditure, of energy occurs due to different processes (e.g., aerobic vs anaerobic) and acting on different kinds of energetic molecules (e.g., carbohydrates or fats). The aerobic combustion of hydrocarbons—such as carbs and fats—requires oxygen, as discussed in the previous section on rate of whole-body oxygen consumption (VO_2). Energy can also be expended at a higher rate, although less sustainably, by anaerobic processes that do not directly require oxygen. Physical activity promotes the use of molecular fuels, first within the contracting muscles themselves, that can induce a systemic exchange between tissues usually requiring transportation into and out of the blood. Storage of carbohydrates is limited in humans but importantly occurs in the liver and muscles, while fat storage has a high capacity and occurs mainly in the liver, muscles, and adipocytes (fat cells). Under the umbrella of metabolic health, cardiometabolic disease (CMD) refers to a clustering of distinct risk factors. The Consortium for Spinal Cord Medicine (CSCM) clinical practice guidelines for CMD in people with SCI focus on four main categories of metabolic health: obesity, dysglycemia, dyslipidemia, and hypertension. (See the Introduction for more details.) Importantly, the CSCM CMD guidelines recommend physical exercise as a primary treatment strategy for the management of CMD in SCI.

3.3.1 Arm Cycle Ergometry (ACE) Training

Our definition of arm cycle ergometry (ACE) can be found above in the Cardiorespiratory Health and Endurance section.

Table 8. Effect of Arm Cycle Ergometry Training on Blood Serum Parameters

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Nightingale et al. (2017) U.K. RCT PEDro=5 $N_{Initial}=24$, $N_{Final}=21$	Population: Mean age: 47±8yr; Gender: males=15, females=6; Level of injury: C1-T5=12, T6-L5=9; Level of severity: AIS: A-B=18, AIS C-D=3; Mean time since injury: 17±5yr. Intervention: Participants were randomized into either a 6wk prescribed home-based exercise intervention (INT) or control group (CON). Participants allocated to the exercise group completed 4, 45min moderate-intensity (60-65% $_{peak}$ oxygen uptake (VO_{2peak})) arm-crank exercise sessions/wk. Outcome Measures: Physical activity energy expenditure, Body composition, Metabolic regulation, VO_{2peak}, power output, Homeostasis Model Assessment of Insulin Resistance (HOMA2-IR), Fasting serum concentrations,	1. The moderate-intensity upper-body exercise INT group significantly ↑ physical activity energy expenditure and minutes spent performing moderate-to-vigorous intensity physical activity relative to the CON group ($p<0.01$). 2. Body mass significantly ↓ from baseline to follow-up when all participants were considered ($p<0.05$). The absolute change was not different between the two groups ($p=0.6$). 3. The INT group significantly ↑ ($p<0.001$) VO_{2peak} and $_{peak}$ power output, whereas these outcomes remained unchanged in the CON group. 4. Changes in fasting serum insulin concentrations and the HOMA2-IR were different between the two groups ($p<0.044$). The INT group significantly ↓ fasting serum insulin concentrations and HOMA2-IR ($p<0.035$), whereas

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	and Adipose tissue gene expression (ATGL).	these outcomes were unchanged in the CON group. 5. ATGL was down-regulated over the course of six weeks (p=0.038).
Kim et al. (2015) Korea RCT PEDro=5 N=15	Population: 15 participants (9 males, 6 females) with SCI (ASIA-A &B, C5-T11). Mean age was 33 and all participants had SCI for more than 6 months. 8 participants allocated to the hand-bike exercise group, 7 participants to the control group. Intervention: Participants exercised with the indoor-hand bike for 60min/day, 3 days/week, for 6 weeks under supervision of an exercise trainer. Participants maintained a heart rate of 70% of theirmaximum. Exercise intensity was gradually ↑ on a weekly basis using the Borg rating of perceived exertion (RPE level 5 to 7). The control group continued with usual activities. Outcome Measures: Body mass index (BMI), waist circumference, percent body fat, insulin level, homeostasis model assessment of insulin resistance (HOMA-IR) level, upper body muscle	1. Post-intervention, the exercise group showed significant ↓ in BMI, waist circumference, fasting insulin and HOMA-IR levels compared with the control group. 2. The exercise group exhibited significantly lower insulin and HOMA-0R levels, and ↑ in high density lipoprotein cholesterol after the exercise training period compared with baseline levels. 3. The exercise group also showed significant ↑ in $V0_{2peak}$ and upper body strength compared with the control group following intervention. 4. No change in glucose, total cholesterol, triglycerides, or low-density lipoprotein were observed in the exercise group.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	strength (using a dynamometer), $V02_{peak}$, lipid metabolite indices (including cholesterol, triglycerides, high & low density lipoprotein cholesterol levels.	
Bakkum et al. (2015) Netherlands RCT PEDro=6 N=19	Population: 19 participants (18 males, 1 female, C2-L2) with SCI for more than 10 years. Intervention: Participants were randomized to the hybrid or hand cycle group. 9 participants on hybrid cycle and 10 participants on hand cycle during 32 individual training sessions within a period of 16 weeks. The duration of each training session ↑ from 18 to 32 minutes during the program. Outcome Measures: Metabolic syndrome (waist circumference, systolic/diastolic blood pressure, high density lipoprotein cholesterol, triglycerides, and insulin resistance), inflammatory status (C-reactive protein, interleukin -6 & -10), and visceral adiposity (trunk and android fat).	1. For all metabolic components, inflammatory markers, and visceral adiposity, there were no differences over time between the 2 training groups. 2. Overall reductions were found for waist circumference, diastolic blood pressure, insulin resistance, CRP, IL-6, trunk and android fat percentage.
Rosety-Rodriguez et al. (2014) Spain	Population: *Experimental group:* Mean age: 29.6±3.6yr; Time post injury: 54.8±3.4mo.	1. Leptin, TNF-a and IL-6 levels were significantly ↑ in the exercise group (p<0.05) when

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
RCT Pedro=7 N=17	*Control group:* Mean age: 30.2±3.8yr; Mean time since injury: 55.7±3.6mo. Gender: males=17, females=0; Level of injury: T2-L5=17. Intervention: 12wk arm cranking exercise program for 3 sessions/wk. Each training session consisted of warm-up (10-15min), arm crank (20-30min; increasing 2min and 30sec every 3wk) at a moderate work intensity of 50% to 65% of heart rate reserve (starting at 50% and increasing 5% every 3wk), and cool-down (5-10min). Control participants completed assessments but did not take part in a training program. The control group consisted of individuals matched for age, sex, and injury level. Outcome Measures: Plasma levels of leptin, adiponectin, plasminogen activator inhibitor-1 (PAI-1), TNF-a, IL-6, maximum oxygen consumption [$VO2_{peak}$], anthropometric index [AI], waist circumference [WC], and body mass index [BMI].	compared to the control after the exercise intervention. 2. VO_{2peak} was significantly ↑ in the intervention group (p=0.031). Body composition was improved as the AI (p=0.042) and WC (p=0.046) were significantly reduced at the end of the training program. 3. No significant change was observed in BMI after exercise (p=0.72) 4. All other measures were not significantly different between the two groups (p>0.05)
	Population: *Intervention group* (n=9): mean (SD)	1. When compared with baseline results, VO_{2peak} was

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Ordonez et al. (2013) Italy RCT PEDro=8 N=17	age: 29.6(3.6)yr; Gender: males=9, females=0; mean (SD) DOI = 54.8(3.4) mo. *Control group* (n=8): mean (SD) age: 30.2(3.8)yr; Gender: males=8, females=0; mean (SD) DOI = 55.7(3.6)mo; At or below the fifth thoracic level (T5) Intervention: Intervention group performed a 12-week arm-cranking exercise program, 3 sessions/wk, consisting of warming-up (10-15min) followed by a main part in arm-crank (20-30min [increasing 2 min and 30s every 3 wk]) at a moderate work intensity of 50% to 65% of the HR reserve and by a cooling-down period. Outcome Measures: Plasmid levels of total antioxidant status, erythrocyte glutathione peroxidase activity malondialdehyde and carbonyl group levels, physical fitness and body composition	significantly ↑ in the intervention group. 2. Both total antioxidant status and erythrocyte glutathione peroxidase activity were significantly ↑ at the end of the training program. 3. Plasmatic levels of malondialdehyde and carbonyl groups were significantly reduced following training.
Horiuchi & Okita, (2017) Japan Pre-Post N=9	Population: Mean age: 38±10yr; Gender: males=9, females=0; Level of injury: T8-L1=9; Level of severity: AIS A=7, AIS B=2; Mean time since injury: 16±7.1yr. Intervention: Individuals with a SCI)performed 2, 30min sets of arm-	1. Maximum WC, BM, VO_{2peak}, SBP, TG, and PAI-1 significantly improved with the 10-week arm-cranking exercise training (p<0.05). 2. WC, BM, SBP, TG, and PAI-1 ↓, and $_{peak}VO_2$ ↑ after training (p<0.05, respectively).

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	cranking exercises with a 10 min resting interval between them, 4 days/wk for 10 wk at an intensity of 50~70% heart rate reserve (HRR). Outcome Measures: Isometric maximum handgrip (HG), strength, body mass (BM), waist circumference (WC), aerobic capacity ($_{peak}$ VO_2), plasminogen activator inhibitor 1 (PAI-1), systolic blood pressure (SBP), glucose metabolism, and lipid profiles (triglycerides (TG), high-density lipoprotein (HDL) cholesterol).	3. After the 10-week detraining phase, WC, BM, VO_{2peak}, SBP, TG, and PAI-1 accurately recovered with statistical differences between post-training and detraining ($p<0.05$). 4. Spearman rank order analysis revealed that changes in PAI-1 were related to changes in $_{peak}$ VO_2, BM, WC, TG, and HDL cholesterol. 5. Multiple linear regression analysis revealed that WC was the most sensitive factor for predicting changes in PAI-1 ($p=0.038$).
Gorgey et al. (2016) USA Prospective Controlled Trial N=11	Population: Gender: males=11, females=0; Level of injury: C1-T1=3, T2-L5=8; Level of severity: AIS A=8, AIS B=3, AIS C=0. *Exercise group:* Mean age: 40.5±7yr; Mean time since injury: 13.3±9.3yr. *Control group:* Mean age: 35±7.5yr; Mean time since injury: 4.7±4yr. Intervention: Exercise group (n=6) received either: arm cycling ergometry (ACE), (n=3) or Functional electrical stimulation (FES), (n=3). ACE was performed two to three times a week for 16 weeks with ten-minute warm-up, forty minutes of training, and with a ten-	1. In a within group comparison there were significant ↑ in only thigh circumference; 48.5±8 to 52.6±10cm, $p<0.05$ for the exercise group. Measurements for waist, calf, and hip were all non significant. 2. In a between group comparison 2.5yr after the intervention, this thigh circumference was significantly larger in the exercise group. 3. Lean Mass (LM) ↑ by 8.4% and reverted back by 5.4% following 2.5yr of washout period. Whole body LM significantly ↓ at the follow-up visit compared to both the baseline visit ($p=0.015$) and the

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	minute cool down. The workload was adjusted as the participant tolerated from 20 to 40 watts to maintain a $_{peak}$ HR at 75% of their maximum HR. The participant was encouraged to maintain an exercise rate of 50 revolutions per minute. FES cycling (n=3) was performed with bilateral stimulation of the quadriceps, hamstrings, and gluteal muscles. Muscles were stimulated sequentially at 60 Hz with current amplitude (140 mA) necessary to complete 40min of cycling at a cadence of 50 revolutions per min (RPM) with progressively greater resistance over the course of training. Each session included 10min of passive warm-up and cool down. Controls (n=5) did not receive any exercise intervention. Outcome Measures: Anthropomorphic measurements, body composition, Basal Metabolic Rate (BMR) and blood lipid profiles for cholesterol, high-, low-density lipoproteins, triglycerides.	post-intervention visit (p=0.054) in the exercise group, with no changes in the control group. 4. Blood lipid profiles were all non significant in both within group comparison and between group comparison at 2.5yr follow up.
El-Sayed et al.	Population: 5 SCI, lesion	1. Training improved HDL but

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
(2005) UK Pre-Post N=12	below T10, age 32yr; 7 AB controls, age 31yr. Intervention: Arm ergometry, 30 min/d (60%–65%VO_{2peak}), 3 d/wk, 12 wks. Outcome Measures: $VO_{2peak,\ peak}$ HR, $_{peak}$ workload, total cholesterol (TC), triglycerides, HDL.	did not alter TC or triglycerides.
HIIT vs MICT		
Graham et al. (2019) USA RCT PEDro=5 $N_{Initial}$=9, N_{Final}=7	Population: Gender: males=6, females=1; Mean time since injury: >3 yr. *Intervention group:* Mean age: 49.4±13yr; Level of injury: C6=1, C8=1, T8=1, L1=1; Level of severity: AIS A=1, B=3. *Control group:* Mean age: 51.3±1.2yr; Level of injury: C7=1, T6=1, T8=1, T12-L1=1; Level of severity: AIS A=1, B=1, D=1. Intervention: Subjects were randomly allocated to either the intervention group or the control group. The intervention group participated in high-intensity interval training (HIIT), whereas the control group performed moderate-intensity training (MIT). Both groups performed training on an arm ergometer. The intervention group trained for 20 min (30s x 4 repeats;	1. There were no significant differences between groups for body composition related metrics. 2. There was a significant interaction effect for arm fat percentage (p=0.043) showing MIT had a lower arm fat percentage. 3. There was a significant effect of time on QUICKI, muscle strength in the chest press (0.035) and latissimus pulldowns (p=-0.021) exercises. Additionally, there was a significant interaction effect for chest press in favour of MIT. 4. No significant changes in blood lipids or HOMA-IR.

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
	4 min rest 2 sessions per week), 2x/wk, whereas the control group trained for 30 min continuous exercise, 3x/wk. Both groups trained for 6wk. Assessments were taken at baseline, and post-intervention Outcome Measures: fat mass, lean mass, percent body fat, percent arm fat, percent leg fat, blood pressure, resting energy expenditure, oral glucose tolerance test, quantitative insulin sensitivity check index (QUICKI), blood lipids, strength assessment, $_{peak}$ oxygen uptake, $_{peak}$ power on ergometer, OGTT, HOMA-IR	
de Groot et al. (2003) Netherlands RCT PEDro=7 N=6	Population: 4 male, 2 female, C5-L1, AIS A (*n* = 1), B (*n* = 1), and C (*n* = 4), age 36yr, 116 d post-injury. Intervention: Randomized to low-intensity (50%–60% HRR) or high-intensity (70%–80% HRR) arm ergometry, 20 min/d, 3 d/wk, 8 wks. Outcome Measures: VO_{2peak}, insulin sensitivity, blood glucose.	1. There was a significant difference in insulin sensitivity between groups, with a non-significant decline in the high-intensity group and a significant improvement in the low-intensity group with training. 2. A positive correlation between VO_{2peak} and insulin sensitivity ($r = 0.68$, $p = 0.02$).

Discussion

Ten studies have investigated the effect of arm-crank exercise on metabolic health. There is level 1a evidence arising from five studies (4 RCTs, 1 pre/post) that arm-crank exercise 2-3 times per week for 6-12 weeks improves insulin resistance. With respect to the effect of arm-crank exercise on lipids, the evidence is less clear. One RCT and one prospective controlled trial found that arm-crank exercise does not impact blood lipids, whereas on additional prospective control trial and one pre-post trial found arm exercise improves blood lipids as defined by increased HDL and/or reduced triglycerides. Since there appears to be no consistent differences in participant demographics, exercise intensity, or exercise duration across studies future research in this area is needed.

Conclusion

There is level 1a evidence (Rosety-Rodriguez et al. 2014) that 12 weeks of arm-crank exercise (20-45 min/day, 50-65% heart rate reserve) improves metabolic/immune function in those with mid-to-low thoracic SCI.

There is level 1a evidence (Ordonez et al. 2013) that 12 weeks of arm-crank exercise (20-45 min/day, 50-65% heart rate reserve) improves metabolic function in those with low thoracic SCI.

There is level 1a evidence (De Groot et al. 2003) that 8 weeks of 3d/k arm-exercise at a low intensity (50-60% heart rate reserve), but not high intensity (70-80% heart rate reserve), improves insulin sensitivity.

There is level 1b evidence (Graham et al. 2019) that both that 6 weeks of both HIIT (30s x 4 repeats; 4 min rest 2 sessions per week) and MICT (30 min continuous exercise, 3x/wk) are both effective in reducing QUICKI, but not HOMA-IR or blood lipids.

There is level 1b evidence (Nightingale et al. 2017) that 6 weeks of 4d/wk arm crank exercise (45min/day, 60-65% VO2peak) improves markers of insulin resistance in individuals with various levels and severities of SCI.

There is level 1b evidence (Kim et al. 2015) that 6 weeks of 3d/wk hand-bike exercise (60 min/day, 70% peak heart rate) improves markers of glucose tolerance and blood lipids in individuals with various levels and severities of SCI.

There is level 1b evidence (Bakkum et al. 2015) that 16 weeks of hand-bike exercise (18-32 min/day) improves markers of inflammation and immune function, but not metabolic function in individuals with various levels and severities of SCI.

There is level 2 evidence (Gorgey & Lawrence, 2016) that 16 weeks of 2-3d/wk arm-crank exercise (40min/day, 75% peak heart rate) improves thigh lean mass but not blood lipids in individuals with various levels and severities of SCI.

There is level 4 evidence (Horiuchi & Okita, 2017) that 10 weeks of 4d/wk arm-crank exercise (2 x 30min/day, 50-70% heart rate reserve) improves metabolic fuction in those with low-thoracic/lumbar SCI.

There is level 4 evidence (El-Sayed & Younesian, 2005) that 12 weeks of 3d/wk arm-crank exercise (30 min/day, 60%–65%VO2peak) improves metabolic function in those with low-thoracic SCI.

3.3.2 Neuromuscular Electrical Stimulation (NMES) Training

Our definition of neuromuscular electrical stimulation (NMES), and how we use the term “functional electrical stimulation (FES)”, can be found above in the Cardiorespiratory Health and Endurance section.

Table 9. Effect of Various Forms of Neuromuscular Electrical Stimulation Training on Blood Serum Parameters

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Functional Electrical Stimulation Leg Cycling Exercise (FES-LCE)		
Gorgey et al. (2016) USA Prospective Controlled Trial N=11	Population: Gender: males=11, females=0; Level of injury: C1-T1=3, T2-L5=8; Level of severity: AIS A=8, AIS B=3, AIS C=0. *Exercise group:* Mean age: 40.5±7yr; Mean time since injury: 13.3±9.3yr. *Control group:* Mean age: 35±7.5yr; Mean time since injury: 4.7±4yr. Intervention: Exercise group (n=6) received either: arm cycling ergometry (ACE), (n=3) or Functional electrical	1. In a within group comparison there were significant ↑ in only thigh circumference; 48.5±8 to 52.6±10cm, p<0.05 for the exercise group. Measurements for waist, calf, and hip were all non significant. 2. In a between group comparison 2.5yr after the intervention, this thigh circumference was significantly larger in the exercise group.

	stimulation (FES)-LCE, (n=3). ACE was performed two to three times a week for 16 weeks with ten-minute warm-up, forty minutes of training, and with a ten-minute cool down. The workload was adjusted as the participant tolerated from 20 to 40 watts to maintain a $_{peak}$ HR at 75% of theirmaximum HR. The participant was encouraged to maintain an exercise rate of 50 revolutions per minute. FES cycling (n=3) was performed with bilateral stimulation of the quadriceps, hamstrings, and gluteal muscles. Muscles were stimulated sequentially at 60 Hz with current amplitude (140 mA) necessary to complete 40min of cycling at a cadence of 50 revolutions per min (RPM) with progressively greater resistance over the course of training. Each session included 10min of passive warm-up and cool down. Controls (n=5) did not receive any exercise intervention. Outcome Measures: Anthropomorphic measurements, body composition, Basal Metabolic Rate (BMR) and blood lipid profiles for cholesterol, high-, low-density lipoproteins, triglycerides.	3. Lean Mass (LM) ↑ by 8.4% and reverted back by 5.4% following 2.5yr of washout period. Whole body LM significantly ↓ at the follow-up visit compared to both the baseline visit (p=0.015) and the post-intervention visit (p=0.054) in the exercise group, with no changes in the control group. 4. Blood lipid profiles were all non significant in both within group comparison and between group comparison at 2.5yr follow up.

Van Duijnhoven et al. (2010) Switzerland Pre-Post N=9	Population: Mean age: 41yr; Gender: males=9, females=0; Level of injury: complete lesions C5-T11=7, incomplete lesion at C5=2; Level of severity: AIS A=7, AIS B=1, AIS D=1; Mean time since injury: >4yr. Intervention: Participants completed 8-week of Functional Electrical Stimulation (FES) exercise training. For FES a computer-controlled leg cycle ergometer was used and electrical stimulation (450µs, frequency 30Hz, 140mA), pedaling rate approximately 50rpm). A total of 20 sessions were completed (2/wk for 4wk then 3/wk for 4wk). Assessments were done at baseline and post intervention, as well as before and after first FES cycling session. Outcome Measures: Malondialdehyde levels (MDA), Superoxide dismutase (SOD) levels and Glutathione peroxidase enzyme (GPx) levels.	1. After a single FES training and after 8 weeks of FES training, there were no significant differences in MDA, SOD or GPx levels.
Jeon et al. (2002) Canada Pre-Post N=7	Population: 5 male, 2 female, motor complete, C5-T10, ages 30-53yr, 3–40yr post-injury. Intervention: FES leg-cycle training, 30 min/d, 3 d/wk, 8 wks. Outcome Measures: oral glucose tolerance test (OGTT), glucose and insulin levels, glucose utilization, insulin sensitivity and levels.	1. There were significantly lower (14.3%) 2-hr OGTT glucose levels after 8wk of training.

Mohr et al. (2001) Denmark Pre-Post N=10	Population: 8 male, 2 female, 6 tetraplegia, 4 paraplegia, C6-T4, age 35yr, 12yr post-injury. Intervention: FES-LCE, 30 min/d, 3 d/wk, 12 months; 7 participants completed an additional 6 months (1 d/wk). Outcome Measures: insulin-stimulated glucose uptake, oral glucose tolerance test (OGTT), GLUT 4 glucose transporter protein.	1. Insulin-stimulated glucose uptake rates ↑ after intensive training, suggesting improved insulin sensitivity. 2. With the reduction in training, insulin sensitivity ↓ to a similar level as before training. GLUT-4 content in the quadricep muscle significantly ↑ by 105% after intense training and ↓ again with the training reduction. 3. The participants had impaired glucose tolerance before and after training, and neither glucose tolerance nor insulin responses to OGTT were significantly altered by training.
Hjeltnes et al. (1998) Sweden Pre-Post N=5	Population: 5 males, C5-C7, all complete AIS A, age 35yr, 10yr post-injury. Intervention: Electrically stimulated leg cycling exercise, 7 d/wk, 8wk. Outcome Measures: peripheral insulin sensitivity, whole body glucose utilization, glucose transport, phosphofructokinase, citrate synthase, hexokinase, glycogen synthase, blood glucose, plasma insulin.	1. After training, insulin-mediated glucose disposal was ↑ by 33%. There was a 2.1-fold ↑ in insulin-stimulated glucose transport. 2. Training led to marked ↑ in protein expression of GLUT4 (glucose transporter) (378%), glycogen synthase (526%), and hexokinase II (204%) in the vastus lateralis muscle. 3. Hexokinase II activity ↑ 25% after training.
FES Rowing (FES-ROW)		
Jeon et al. (2010) Canada Pre-Post N=6	Population: 6 male participants with paraplegia participated in the study (mean age, 48.6 ± 6.0 y; mean weight, 70.1 ± 3.3 kg; injury levels between T4-5 and T10).	1. VO_{2peak} ↑ from 21.4 ± 1.2 to 23.1 ± 0.8 mL/kg/min (P = 0.048). 2. Plasma leptin levels were significantly ↓ after the training (pre: 6.91 ± 1.82 ng/dL

	Intervention: 12 weeks of FES-rowing exercise training 3 to 4 times a week (600–800 kcal). Outcome Measures: VO_{2peak}, plasma leptin, insulin, and glucose levels, insulin sensitivity, body composition.	vs. post: 4.72 ± 1.04 ng/dL; P = 0.046). 3. Plasma glucose and leptin levels were significantly ↓ after exercise training by 10% and 28% (P = 0.028), respectively. 4. HOMA-IR did not reach statistical significance.
Solinsky et al. (2020) USA Pre-Post N=40	Population: Mean age: 34.1±12.4yr; Gender: males=34, females=6; Level of injury: C1-T1=21, T2-L5=18 Unknown=1; Level of severity: AIS A=19, AIS B=8, AIS C=5, AIS D=2, AIS Unknown=6; Mean time since injury: 41.4±87.4mo. Intervention: Hybrid Functional Electrical Stimulation (FES) on quadriceps and hamstrings during rowing exercise with a goal of 2-3 sessions/wk at a goal heart rate of over 75% of maximum, quantified during baseline. Individuals averaged 42.1± 22.0min of hybrid-FES rowing/wk, mean 1.69 sessions/wk for 6mo. Outcome Measures: VO_{2peak}, Cardiometabolic Disease (CMD) indicator, SCI specific-Body Mass Index, A1C, free insulin, fasting glucose, LDL, HDL, total cholesterol, triglycerides.	1. VO_{2peak} ↑ and AIC ↓ significantly, $p<0.001$ and $p=0.01$, respectively. 2. Non-significant ↓ in prevalence of cardiometabolic disease ($p=0.70$), BMI ($p=0.27$) Triglycerides ($p=0.12$), LDL ($p=0.08$), HDL ($p= 0.48$), cholesterol ($p=0.11$), except for A1C which was reduced over the 6 month period 3. Subdividing into those with para- or tetraplegia showed, neither group ↓ their prevalence of cardiometabolic disease to a significant degree ($p>0.58$ for both). The exception to this were ↑ in both LDL and insulin resistance (via HOMA-2) in the sub-group with paraplegia ($p<0.05$).
Neuromuscular Electrical Stimulation Resistance Training (NMES-RT)		
Gorgey et al. (2019) USA	Population: Mean age: 37 ± 12 yr in experimental group (n=11), 35 ± 8 yr in	1. BMI and supine thigh circumference were significantly ↑ in the

RCT PEDro=7 N=22	control group (n=11); Gender: males=22, females=0; Level of injury: C1-T1=NR, T2-L5=NR; Level of severity: AIS A=16, AIS B=6, AIS C=0; Mean time since injury: 10 ± 9 in experimental group, 7 ± 6 in control group Intervention: All subjects received 2–6 mg/day of testosterone (TRT) administered through transdermal testosterone patches. Experimental group (TRT-RT), received additional progressive resistance exercise of the knee extensor muscle groups and with neuromuscular electrical stimulation (NEMS). NMES was applied over thigh at Biphasic waveform, 30 Hz, 450 μs pulse width, current intensity enough to elicit full knee extension. RT was performed two times per week for the study duration of 16 weeks. Outcome Measures: Body mass index (BMI) and body composition, Basal Metabolic Rate (BMR), lipid panel, serum testosterone, adiponectin, inflammatory (C-Reactive Protein, CRP, Tumour Necrosis Factor-α TNF-α, Free fatty Acids, FFA) and anabolic biomarkers (IGF-1 and IGFBP-3) glucose effectiveness (Sg) and insulin sensitivity (Si).	experimental group relative to the control, p=0.004 and p=0.01 respectively. 2. Total visceral adipose tissue, BMR, Si, IGF-1, IGFBP-1 demonstrated no significant group differences (p>0.05) 3. Neither intervention appeared to significantly influence any parameters of the lipid panel, CRP, TNF-α or FFA (p>0.05). 4. A significant interaction was noted in the circulating adiponectin between TRT+RT (n=8) and TRT (n=10) groups for both absolute (P=0.024) and adjusted (adiponectin adjusted to body weight: P= 0.022 & adiponectin adjusted to lean mass: P=0.036)

Ryan et al. (2013) USA Pre-Post N=14	Population: 11M;3F with motor complete SCI C4-T7 level; AIS A or B; mean (SD) age: 26.7(4.7)yr; mean (SD) time post injury: 7.7 (6.5)yr. Intervention: Participants performed NMES resistance exercise training of the knee extensor muscles twice weekly for 16 weeks. Four sets of 10 knee extensions were performed using neuromuscular electrical stimulation. Legs were alternated after 10 repetitions, and training sets were separated by 2 min. Outcome Measures: plasma glucose and insulin; thigh muscle and fat mass; quadriceps and hamstrings muscle size and composition; muscle oxidative metabolism.	1. Mean (SD) muscle mass ↑ in all participants (39(27)%). The mean change (SD) in intramuscular fat was 3(22)%. 2. Phosphocreatine mean recovery time constants (SD) were 102(24) and 77(18)s before and after electrical stimulation-induced resistance training, respectively. 3. No improvement in fasting blood glucose levels, homeostatic model assessment calculated insulin resistance, 2-hour insulin, or 2-hr glucose was observed.

Discussion

Seven studies have investigated the effect of FES cycling or rowing exercise training interventions on blood serum parameters. With the exception of one small prospective controlled trial (n=3) all studies utilized a simple pre to post design. From the pre-post studies, there is level 4 evidence that FES improves glucose tolerance, as determined via either H1C or via oral glucose tolerance testing, but not markers of anti-oxidant function. Moreover, two studies have demonstrated that FES improves insulin sensitivity and Glut4 content in the leg muscles. Glut4 is responsible for insulin mediated glucose into skeletal muscle cells. Of the 2 studies that have investigated Neuromuscular Electrical Stimulation Resistance Training (NMES-RT) one RCT demonstrated a positive impact of NMES-RT on adiponectin levels, but neither study found any change in glucose tolerance of insulin resistance.

Conclusion

There is level 1a evidence (Gorgey et al. 2019) that 16 weeks of 2d/wk of knee extensor resistance exercise with neuromuscular electrical stimulation in combination with testosterone patches does not improve markers of immune function or blood lipds, but does improve adiponectin in those with thoracic or lumbar SCI.

There is level 2 evidence (Gorgey & Lawrence 2016) that 16 weeks of 2-3d/wk FES-leg cycling exercise (40min of cycling at a cadence of 50 revolutions per min (RPM)) improves thigh lean mass but not blood lipids in individuals with various levels and severities of SCI.

There is level 4 evidence (Van Duijnhoven et al. 2010) that 8 weeks of 2-3d/wk FES-leg cycling exercise (60 min/day, cycling at a cadence of 50 revolutions per min (RPM)) does not improve markers of anti-oxidant function in individuals with various levels and severities of SCI.

There is level 4 evidence (Jeon et al. 2002) that 8 weeks of 3d/wk FES-leg cycling exercise (30min/day) improves glucose tolerance in individuals with various levels and severities of SCI.

There is level 4 evidence (Mohr et al. 2001) that 12 months of 3d/wk FES-leg cycling exercise (30min/day) improves insulin stimulated glucose uptake and GLUT-4 content in the quadricep muscle in individuals with cervical or high-thoracic SCI.

There is level 4 evidence (Hjeltnes et al. 1998) that 8 weeks of 7d/wk FES-leg cycling exercise improves insulin mediated glucose disposal and GLUT-4 content in the quadricep muscle in individuals with cervical SCI.

There is level 4 evidence (Jeon et al. 2010) that 12 weeks of 3-4d/wk FES-rowing exercise (600–800 kcal) improves plasma leptin and glucose but not glucose tolerance in those with mid-to-low thoracic SCI.

There is level 4 evidence (Solinsky et al. 2020) that 6 months of 1-2d/wk FES-rowing exercise (>75% peak heart rate) improves hemoglobin A1C but not blood lipids in those with various levels and severities of SCI.

There is level 4 evidence (Ryan et al. 2013) that 16 weeks of 2d/wk of NMES resistance exercise training of the knee extensor muscles doe not improve insulin resistance or glucose tolerance.

3.3.3 Body Weight Supported Treadmill Training (BWSTT)

Our definition of body weight support treadmill training (BWSTT) can be found above in the Cardiorespiratory Health and Endurance section.

Table 10. Effect of Body Weight Support Treadmill Training on Blood Serum Parameters

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Turiel et al. (2011) Italy Pre-Post N=14	Population: SCI Group: Mean age 50.6 ± 17.1yr; Gender: males=10, females=4; 2-10yr post-injury; 9 paraplegia) with lost sensorimotor function caused by incomplete SCI. Intervention: BWSTT assisted with robotic driven gait orthosis for 60 min sessions, 5 d/wk, 6wk, with 30-50% of body weight supported (reduced as tolerated). Outcome Measures: Left ventricular function, coronary blood flow reserve (via dipyrsidamole stress echo), plasma asymmetric dimethylarginine (ADMA) (marker of vascular abnormalities observed in cardiovascular disease and ageing), and plasma inflammatory markers.	1. Significant improvement in the left ventricular diastolic function (i.e., a reduction in isovolumic relaxation time and deceleration time was observed following the training. 2. Significant ↑ in coronary reserve flow and reduced plasma ADMA levels was observed in the follow up. 3. Significant reduction in the inflammatory status (C-reactive protein and erythrocyte sedimentation rate).
Phillips et al. (2004) Canada Pre-Post N=9	Population: 8 male, 1 female, incomplete AIS C, C4-T12, 8.1 yrs post-injury. Intervention: Body-	1. Reduction in the area under the curve for glucose (-15%) and insulin (-33%). 2. The oxidation of exogenous

	weight–supported treadmill walking, 3 d/wk, 6 months. Outcome Measures: whole-body dual-energy X-ray absorptiometry (to capture body composition and bone density), GLUT4 protein abundance, hexokinase activity, oral glucose tolerance tests, glucose oxidation, CO2 breath analysis.	(ingested) glucose and endogenous (liver) glucose ↑ (68% and 36.8%, respectively) after training. 3. Training resulted in ↑ muscle glycogen, GLUT-4 content (glucose transporter) (126%), and hexokinase II enzyme activity (49%).
Stewart et al. (2004b) Canada Pre-Post N=9	Population: 8 male, 1 female, incomplete AIS C, C4-T12, 8.1yr post-injury. Intervention: Body-weight–supported treadmill training, 3 d/wk, 6 months. Outcome Measures: ambulatory capacity (Wernig Walking Scale), cholesterol, HDL, LDL, triglycerides.	1. There were significant reductions in TC (-11.2%), LDL (-12.9%), and TC/HDL (-19.8%).

Discussion

Three pre-post studies have investigated the role of BWSTT on cardiometabolic function. All 3 studies demonstrate level 4 evidence that BWSTT improves various markers of cardiometabolic function including reduced insulin levels, reduced HOMA-IR, improved lipids, and reduced inflammation.

Conclusion

There is level 4 evidence (Turiel et al. 2011) that 6 weeks of 5d/wk BWSTT (60 min/day, 50-60% weight support) improves cardiac diastolic function and reduces inflammation in individuals with incomplete paraplegia.

There is level 4 evidence (Phillips et al. 2004) that 6 months of 3d/wk BWSTT improves glucose tolerance and increases GLUT-4 muscle content in individuals with various levels and severities of SCI.

There is level 4 evidence (Stewart et al. 2004b) that 6 months of 3d/wk improves blood lipids in individuals with various levels and severities of SCI.

3.3.4 Other Physical Activity

Our definition of “Other Physical Activity” can be found above in the Cardiorespiratory Health and Endurance section.

Table 11. Effect of Other Forms of Physical Activity and Exercise on Blood Serum Parameters

Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Behavioural Change		
(Montesinos-Magraner et al. 2018) Spain Observational N=67	Population: Complete motor SCI (T2-T12). *Inactive group (n=30):* Mean age: 50.63yr; Gender: males=20, females=10; Mean time since injury: 15.77yr. *Active group (n=37)*: Mean age: 43.4yr; Gender: males=31, females=6; Mean time since injury: 17.76yr. Intervention: Participants who were full time manual wheelchair users, wore an accelerometer attached to their non-dominant wrist for a period of 1 week (actigraph model GT3X). Participants were divided into active (at least 60min moderate to vigorous physical activity per week) or inactive groups. Outcome Measures: Physical activity levels, risk factors for metabolic	1. The inactive group, compared to the active group, had significantly less METS (MD -0.13), and less minutes per day of light (-95.73), moderate (-22.89) and moderate-to-vigorous (-23.10) activity (all p<0.001), as well as vigorous exercise (-0.21, p=0.04). 2. There was an association between PA group and diabetes mellitus (p=0.047); active group was 7.2 times less likely to have diabetes than inactive group. 3. 63% of inactive group had two or more risk factors for metabolic syndrome and 59% of active group had none or only a single risk factor.

	syndrome.	
Nooijen et al. (2017) The Netherlands RCT PEDro=6 $N_{initial}=45$; $N_{final}=39$	Population: Intervention group: Mean age: 44yr; Gender: males=17, females=3; Level of injury: Tetraplegia=7, Paraplegia (13); Mean time post-injury: 139 days Control group: Mean age: 44yr; Gender: males=16, females=3; Level of injury: Tetraplegia=6, Paraplegia=13; Mean time post-injury: 161 days Intervention: Intervention group: A behavioural intervention promoting physical activity, involving 13 individual sessions delivered by a coach trained in motivational interviewing, beginning 2mo before and ending 6mo after discharge from inpatient rehabilitation. Control group: Regular rehabilitation Outcome Measures: Physical capacity as determined during a maximal exercise test, body mass index (BMI), blood pressure, fasting lipid profile, social participation (IMPACT-S), 36-item Short Form Health Survey questionnaire (SF-36).	1. Diastolic blood pressure improved significantly 12 months after discharge (p=0.01), 2. Total cholesterol (p=0.01) and low-density lipoprotein cholesterol (p=0.05) improved significantly 12 months after discharge 3. Participation improved significantly 12 months after discharge (p<0.01). 4. No significant differences in QoL and mental health were observed (p>.05)
Myers et al. (2012) USA Pre-Post N=26	Population: Mean age: 56.92±5.74yr; Mean time since injury: 23.8±12.3yr. Intervention: Risk intervention program including frequent telephone contact and in-	1. Weight was reduced slightly at each follow-up point but was significantly lower only for the comparison between baseline and 6mo (p=0.004).

	person visits by a dietician, physical therapist, and exercise physiologist. Very generic, nonspecific, activity advice. Participants were contacted by phone weekly during the first 6wk, then at 8wk and at 3, 4, 5, and 6mo. Following this was complete evaluations in the spinal cord injury (SCI) Center at 12, 18, and 24mo. Outcome Measures: Homeostasis model of assessment-insulin resistance (HOMA-IR), insulin levels, Body Mass Index (BMI), total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides.	2. 90 and 94% of participants exhibited reductions in insulin level, and 85 and 88% of subjects exhibited reductions in HOMA-IR at 6mo and 12mo, respectively (<0.01 for all). 3. Among lipid profiles, total cholesterol/HDL ratio was lower at the 6mo evaluation (p=0.05) and triglycerides tended to be lower at each evaluation (~10-20%). 4. No differences were observed in objective or subjective estimates of physical activity patterns at any of the measurement intervals.
Totosy de Zepetnek et al. (2015) Canada RCT PEDro=4 $N_{initial}$=23 N_{final}=17	Population: *Physical Activity Guidelines (PAG)* Age=39±11yr.; Gender: males=12, females=0; Level of injury: C3-T10; Level of severity: AIS A-B=3, C-D=9; Time since injury=15±10yr. *Control Group* Age=42±13yr.; Gender: males=9, females=2; Level of injury: C1-C11; Level of severity: AIS A-B=5, C-D=6; Time since injury=9±10yr. Intervention: Participants were randomized to either an intervention group (PAG; n=12) in which they completed supervised 60min exercise sessions, 2 times per week for 16 weeks, or	1. Traditional CVD Risk Factors and Blood Biomarkers: 2. Group X time interaction for WC (p=0.03) and BMI (p=0.02). 3. No change in fasting insulin, adipokines, inflammatory markers, and thrombotic markers in either group. 4. Body Composition 5. There was a group X time interaction for WBM (p=0.03), WBF (p=0.04), and VAT (p=0.04). 6. Trend toward an interaction for LF (p=0.056). 7. No changes observed in WBL. 8. Arterial Structure and Function 9. Group X time interaction was found for CD (p=0.05).

	a control group (n=11) in which they maintained their existing physical activity and were provided no guidance or training intensity. Outcome Measures: Blood biomarkers (hemoglobin (HvA1c), triglycerides, total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, total cholesterol/high-density lipoprotein cholesterol), fasting insulin, adipokines (leptin, adiponectin), proinflammatory markers (IL-6, TNF-a), and prothrombotic markers (PAI-1)), Body composition (whole body mass (WBM), leg fat (LF), body mass index (BMI), waist circumference (WC), whole-body fat (WBF), whole-body lean (WBL), and visceral adipose tissue (VAT)), Arterial structure and function (Heart rate (HR) and blood pressure (BP) were monitored continuously. Carotid pulse pressure (CPP), carotid distensibility (CD), intima media thickness (IMT), lumen diameter (LD), and wall-to-lumen ratio (WLR), central and peripheral (arm, leg) pulse wave velocity (PWV), brachial (BA) and superficial femoral artery (SFA) endothelial-dependent (flow-	10. No interactions were found for other measures of carotid artery structure (CPP, IMT, WLR), indices of regional stiffness (central, arm, leg PWV), or vascular function (BA, SFA, endothelial dependent [FMD] or independent [NTG] vasodilation).

	mediated dilation [FMD]) and endothelial-independent (NTG) vasodilation.	
Jorgensen et al. (2019) Sweden Observational N=123	Population: Mean Age=63±9yr; Gender: Males=87, Females=36; Level of Injury: C1-L5; Severity of Injury: AIS A-C=63, D=60; Mean Time Since Injury=24±12yr. Intervention: Not applicable. Review of data from the Swedish Aging with Spinal Cord Injury Study to assess participation in leisure time physical activity (LTPA) and cardiovascular risk factors among older adults with long-term spinal cord injury. Outcome Measures: Physical activity recall assessment for people with SCI (PARA-SCI), body mass index (BMI), waist circumference, blood pressure, blood glucose and lipids.	1. More minutes per day of moderate-to-heavy LTPA was significantly associated with a lower BMI (p=0.001) and a lower waist circumference (p=0.009). 2. No other significant associations were found between cardiovascular risk factors and moderate-to-heavy LTPA. 3. Individuals with tetraplegia experienced significantly higher systolic blood pressure with increasing minutes per day of total LTPA (p=0.041). 4. No other significant associations were found between cardiovascular risk factors and total LTPA.
Schreiber et al. (2018) Brazil Observational N=41	Population: *Sedentary (S-SCI) group (n=16)*: Mean age: 34.0±7.6yr; Mean time since injury: 8.2±3.0yr. *Physically Active (PA-SCI) group (n=25):* Mean age: 30.6± 6.2yr; Mean time since injury: 9.7±4.5yr. Gender: males=41, females=0; Level of injury: C1-T1=21, T2-L5=20; Level of injury: tetraplegia=16; paraplegia=25. Level of severity: AIS A=36, AIS B=4, AIS C=1.	1. There were no statistically significant differences in the plasmatic levels of any of the adipocytokines measured (p<0.05). 2. PA-SCI had better LV diastolic function (measured by E/Em ratio, (p=0.024) and lower carotid Intima-media thickness diameter/ratio than S-SCI (p<0.001). 3. Leptin/adiponectin ratio showed stronger correlation with BMI in PA-SCI (r=0.61;

	Intervention: No intervention provided. Subjects were classified for analysis into sedentary S-SCI and physically active PA-SCI groups. Outcome Measures: Clinical, laboratory, carotid ultrasonography and echocardiography analysis. Plasma leptin, adiponectin and plasminogen activating inhibitor-1 (PAI-1) were determined.	p=0.001) than in S-SCI (r=0.45; p=0.08) subjects. 4. Leptin/adiponectin ratio correlated directly with triglycerides (r=0.84, p<0.001) and low-density-lipoprotein cholesterol (r=0.53, p<0.05) in S-SCI participants, but not in PA-SCI individuals (r=0.38; p for interaction <0.05 for triglycerides and r=-0.03; p for interaction=0.08 for low-density-lipoprotein cholesterol).
Buchholz et al. (2009) Canada Observational N=56	Population: *Inactive group (N=28):* Age: 41.1±11.4 yr; Gender: males=22, women=6; Severity of injury: tetraplegia=17, paraplegia=11; Time post injury: 16.5±10.0 yr. *Active (≥25 min/day) group (N=28):* Age: 42.6±13.0 yr; Gender: males=22, women=6; Severity of injury: tetraplegia=9, paraplegia=19; Time post injury: 12.6±10.2 yr. Intervention: None. Outcome Measures: LTPA Physical Activity Recall Assessment for People with SCI (PARA-SCI), body mass index (BMI), %fat mass, %fat-free mass, waist circumference, fasting glucose, fasting insulin, insulin resistance, %insulin resistant.	1. Individuals in the inactive reported no leisure-time physical activity whatsoever. 2. For those in the active group, there was no significant different in minutes of mild, moderate or heavy activity between those with tetraplegia versus paraplegia. 3. The most frequently reported activities in the active group were resistance training (43%), wheeling (43%), and sports or other aerobic exercises (46%). 4. There was no significant difference between groups on %fat mass, %fat-free mass, waist circumference, fasting glucose, fasting insulin, insulin resistance. 5. BMI (p=0.0009) and %insulin resistant (p=0.03) were significantly higher in inactive than active individuals.
Nightingale et al. (2019) UK	Population: Mean age: 44±9yr; Gender: males=27, females=6; Level of severity: AIS: A-B=29, AIS	1. A lower SCI lesion was associated with; a higher BMI (p=0.03), $VO_{2\ peak}$ (absolute, p=0.01 and relative, p=0.027)

Cohort N=33	C-D=4; Mean time since injury: 15±10 yr. Intervention: Participants with a SCI performed an incremental exercise protocol on an electrically braked arm-crank ergometer. Physical activity was monitored through a chest-mounted multi-sensor physical activity monitor (Actiheart^{TM}), in which participants were required to wear the device for >80% of each 24-hour period. Outcome Measures: peak oxygen uptake ($VO_{2\ peak}$), Body Mass Index (BMI), Metabolic regulation (fasting insulin, insulin sensitivity and HOMA2-IR).	and poorer metabolic regulation (fasting insulin, p=0.009; HOMA2-IR, p=0.009 and insulin sensitivity, p=0.038). 2. Longer time since injury was correlated with higher fasting glucose concentrations (p=0.038). 3. Older age was associated with lower $VO_{2\ peak}$ (absolute, p=0.016 and relative, p=0.001). 4. Body composition characteristics (BMI, waist and hip circumference) showed significant (p<0.04), moderate associations with parameters of metabolic regulation, lipid profiles, and inflammatory biomarkers.
	Sport	
Matos-Souza et al. (2016) Brazil Observational N=17	Population: *Sports Group (n=8);* Mean Age=28.3±2.5yr; Gender: Males=8, Females=0; Level of Injury: T9-C5; Severity of Injury: AIS A=7, B=1; Mean Time Since Injury=5.1±1.3yr. *Control Group (No Sports; n=9);* Mean Age=33.7±2.2yr; Gender: Males=9, Females=0; Level of Injury: T8-C4; Severity of Injury: AIS A=8, B=1; Mean Time Since Injury=7.6±1.5yr. Intervention: Not applicable. Prospective observational study to determine whether involvement in adapted sports (6.3 ± 1.1 hr/wk) is associated with long-term	1. At follow-up the control group experienced: significant ↑ in heart rate (p=0.004) and no significant changes in carotid intima-media thickness or diameter (p>0.05). 2. At follow-up the sports group experienced: significant ↓ in carotid intima-media thickness (p=0.001) and diameter (p<0.001). No other variables were significantly different at follow-up.

	changes in carotid atherosclerosis in individuals with SCI. Outcome measures were assessed at baseline and 5yr follow-up. Outcome Measures: Cholesterol, triglycerides, c-reactive protein, blood pressure, heart rate, stroke volume, cardiac output, peripheral vascular resistance, carotid ultrasonography.	
Hubner-Wozniak et al. (2012) Poland Observational N=65	Population: *Sedentary, No SCI (n=19):* Mean Age=30.0±4.2yr; Gender: Males=19, Females=0. *Sedentary, SCI (n=10):* Mean Age=26.9±5.2yr; Gender: Males=10, Females=0; Level of Injury: C5-C7; Severity of Injury: AIS A=9, B=4. *Rugby Players, No SCI (n=22):* Mean Age=23±5yr; Gender: Males=22, Females=0. *Rugby Players, SCI (n=14):* Mean Age=30.5±5.4yr; Gender: Males=14, Females=0; Level of Injury: C5-C7; Severity of Injury: AIS A=7, B=4. Intervention: Not applicable. Cross-sectional analysis to determine the effect of rugby training (4 – 6 hr/wk) on blood antioxidant capacity in individuals with or without SCI. Outcome Measures: Superoxide dismutase (SOD), glutathione reductase (GR), catalase (CAT), glutathione	1. SOD activity was significantly greater in sedentary individuals without SCI, when compared to sedentary individuals with SCI or rugby players without SCI (p<0.05). 2. No significant between group differences were observed between sedentary or rugby players with SCI(p>0.05). 3. Resting levels of CAT and GPX were significantly greater than in active individuals versus sedentary individuals (p<0.001). 4. No significant between group differences were observed for GR activity (p>0.05). 5. Plasma TAS was greater in individuals without SCI, when compared to those without SCI (p<0.01).

	peroxidase (GPX), total antioxidant status (TAS).	
	Combination	
Kim et al. (2019) Korea RCT PEDro=6 $N_{Initial}$=19, N_{Final}=17	Population: Mean Age=36.8±6.9yr; Gender: Males=11, Females=6; Level of Injury: L1-C4; Severity of Injury: AIS A=9, B=7, C=1; Time Since Injury≥1yr. Intervention: Participants were randomized to complete a combined exercise program consisting of aerobic and resistance exercises (60min/d, 3d/wk for 6wk) or usual care. Outcome measures were assessed at baseline and 6wk. Outcome Measures: peak oxygen consumption, body mass index, percent body fat, waist circumference, shoulder abduction /adduction, shoulder flexion/extension, elbow flexion/extension, fasting insulin levels and homeostasis model assessment of insulin resistance (HOMA-IR) levels.	1. Compared to usual care, the exercise program significantly: ↓ the average fasting insulin ($p<0.05$), ↓ HOMA-IR ($p<0.05$), improved HDL cholesterol ($p<0.05$), ↓ waist circumference ($p<0.05$), and improved muscle strength of the shoulder flexors, extensors, adductors. abductors, and elbow flexors ($p<.05$). 2. There were no significant differences between groups ($p>0.05$) on measures of: peak oxygen consumption, lean mass, body fat percentage, total cholesterol and LDL cholesterol.
	Wheelchair Propulsion	
Hooker & Wells (1989) USA Prospective Controlled Trial N=8	Population: Low-intensity group: n = 6, 3 male, 3 female, C5-T10, age 26–36yr, 3 months to 19yr post-injury; moderate-intensity group: n = 5, 3 male, 2 female, C5-T9, age 23–30yr, 2–19yr post-injury. Intervention: Wheelchair	1. No change in lipid levels in low-intensity group. 2. Significant ↑ in HDL and ↓ in triglycerides, LDL, and the TC/HDL ratio in the moderate intensity group.

	ergometry 20 min/d, 3 d/wk, 8wk: low-intensity (50%–60%$_{peak}$ HRR) and moderate intensity (70%–80% HRR$_{peak}$). Outcome Measures: total cholesterol (TC), triglycerides, HDL, LDL.	

Discussion

Two studies have investigated different forms of combined aerobic exercise and resistance training interventions (Kim et al. 2019; Totosy de Zepetnek et al. 2015). The strongest evidence comes from Kim et al. who demonstrated Level 1A evidence that such combined exercise, performed for 60min/d, 3d/wk improved glucose tolerance and HDL cholesterol, whereas similar exercise performed less frequently had no impact on cardiometabolic function (Totosy de Zepetnek et al. 2015). There is provisional, level 1-4 evidence from two studies that demonstrate a behaviour change coaching intervention designed to promote PA improves cholesterol, HOMA-IR, and blood lipids. Three studies have investigated the relationship between LTPA and cardiometabolic function, of which two studies found no associations between LTPA and blood lipids whereas one study found more active individuals had lower markers of inflammation and a smaller proportion of active individuals were insulin resistant. Interestingly, in the only study to assess whether following the SCI-specific physical activity guidelines improves cardiometabolic health, it was reported that the exercise group had no improvement in any marker of cardiometabolic disease. In studies comparing highly-trained wheelchair athletes with SCI against sedentary individuals with SCI, it is consistently reported that the highly-trained individuals have improved vascular function but that blood lipids and anti-oxidant status are not different between cohorts.

Conclusion

There is level 1a evidence (Kim et al. 2019) that 6 weeks of 3d/wk aerobic and resistance training (60min/day) improves insulin resistance, glucose tolerance, and blood lipids in individuals with various levels and severities of SCI.

There is level 1a evidence (Nooijen et al. 2017) that a behavioural change intervention which promotes physical activity (8 months, 13 individual sessions) improves blood lipids in individuals with various levels and severities of SCI.

There is level 1b evidence (Totosy de Zepetnek et al. 2015) that following the SCI-specific physical activity guidelines (i.e., exercise 2d/wk) for 16 weeks does not improve insulin resistance, markers of inflammation, blood lipids or any indices of vascular structure/function.

There is level 2 evidence (Hooker & Wells 1989) that weeks or 3d/wk (20 min/day) of moderate intensity wheelchair propulsion improves blood lipids compared to low-intensity wheelchair propulsion, in individuals with various levels and severities of SCI.

There is level 4 evidence (Myers et al. 2012) that a behavioural change intervention which promotes physical activity (6 months, weekly/monthly telephone) improves insulin resistance and blood lipids in individuals with various levels and severities of SCI.

There is level 5 evidence (Jorgensen et al. 2019) that the amount of moderate to vigorous physical activity is not associated with blood glucose or blood lipid levels in individuals with various levels and severities of SCI.

There is level 5 evidence (Schreiber et al. 2018) that physically active individuals with SCI had better cardiac and vascular function than non-active individuals, but there was no differences in plasma levels of leptin or adiponectin.

There is level 5 evidence (Buchholz et al. 2009) that physically active individuals with SCI had better insulin resistance than inactive individuals.

There is level 4 evidence (Nightingale et al. 2019) that levels of habitual physical activity are not significantly associated with insulin resistance, glucose tolerance or blood lipids, in individuals with thoraco-lumbar SCI.

There is level 5 evidence (Matos-Souza et al. 2016) that chronic exercise training (i.e., taking part in wheelchair sport ~6hr/wk) improves long-term (5yr follow-up) carotid vascular function but not blood lipids in individual with various levels and severities of SCI.

There is level 5 evidence (Montesinos-Magraner et al. 2018) that a greater amount of physical activity may be associated with more METS (MD -0.13), as well as lower risks of diabetes mellitus and metabolic syndrome in individuals with SCI.

There is level 5 evidence (Hubner-Wozniak et al. 2012) that chronic exercise training (taking part in competitive wheelchair rugby) does not improve anti-oxidant status in in individuals with various levels and severities of SCI.

4 Gaps in the Evidence

- There is very little evidence on the effect of physical activity / exercise on the severity of orthostatic intolerance. As such, future interventional studies should seek to determine whether various forms of exercise improves orthostatic tolerance following SCI.
- There is still inconsistent data regarding the effect of various forms of exercise on markers of cardiometabolic health, particularly the effect on exercise on blood lipids.
- Though not specifically discussed here, we are not aware of any studies that have specifically looked at whether there are sex- or age-differences in the response to exercise interventions in people with SCI.
- There is a need to identify target exercise intensity in robotic and/or body-weight supported treadmill training that leads to consistent improvements in cardiorespiratory fitness.
- There is a need to determine a clinically-relevant minimum magnitude of improvement in cardiorespiratory fitness that results in improved functional capacity.
- Few studies have directly compared the effects of different modalities, exercise intensities or volumes of physical activity in individuals with SCI. Larger RCTs with different intervention arms are required to elucidate the optimal dose or type of exercise to improve cardiovascular health in this at-risk population.
- It remains to be seen whether injury characteristics (e.g., neurological level of injury, severity or time since injury) influence the degree of improvement in certain health outcomes.

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