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CHAPTER SEVEN

Cardiovascular Health and Exercise Following Spinal Cord Injury

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Key Points

There is limited evidence that BWSTT can improve indicators of cardiovascular health in individuals with complete and incomplete SCI.

Tetraplegics and paraplegics can improve their cardiovascular fitness and physical work capacity through aerobic exercise training which are of moderate intensity, performed 20-60 min day, at least three times per week for a minimum of six to eight weeks. Resistance training at a moderate intensity at least two days per week also appears to be appropriate for the rehabilitation of persons with SCI. It remains to be determined the optimal exercise intervention for improving cardiovascular fitness.

Interventions that involve FES training a minimum of 3 days per week for 2 months may improve muscular endurance, oxidative metabolism, exercise tolerance, and cardiovascular fitness.

Aerobic and FES exercise training may lead to clinically significant improvements in glucose homeostasis in persons with SCI. Preliminary evidence indicates that a minimum of 30 min of moderate intensity training on 3 days per week is required to achieve and/or maintain the benefits from exercise training.

Aerobic and FES exercise training may lead to improvements in lipid lipoprotein profile that are clinically relevant for the at risk SCI population. The optimal training program for changes in lipid lipoprotein profile remains to be determined. However, a minimal aerobic exercise intensity of 70% of heart rate reserve on most days of the week appears to be a good general recommendation for improving lipid lipoprotein profile in persons with SCI.

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Warburton DER, Sproule S, Krassioukov A, Eng JJ (2008). Cardiovascular Health and Exercise Following Spinal Cord Injury. In Eng JJ, Teasell RW, Miller WC, Wolfe DL, Townson AF, Hsieh JTC, Konnyu KJ, Connolly SJ, Foulon BL, Aubut JL, editors. Spinal Cord Injury Rehabilitation Evidence. Version 2.0. Vancouver: p 7.1-7.34.

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Cardiovascular Health and Exercise Following Spinal Cord Injury

7.1 Introduction

Persons with spinal cord injury (SCI) currently have an increased life expectancy owing to improvements in medical treatment (Rick Hansen Spinal Cord Injury Registry 2004). The majority of SCIs (80%) occur in individuals who are under 30 years of age (ICORD 2003; Rick Hansen Spinal Cord Injury Registry 2004). Therefore, persons with SCI are susceptible to the same chronic conditions across the lifespan as able-bodied persons. In fact, cardiovascular disease (CVD) is the leading cause of mortality in both able-bodied individuals and persons with SCI (Whiteneck et al. 1992). However, there appears to be an earlier onset of CVD and/or an increased prevalence of CVD in persons with SCI (Yekutiel et al. 1989; Whiteneck et al. 1992; DeVivo et al. 1993; Bauman et al. 1999b). The separation of the autonomic nervous system from the superior brain centres after injury results in a series of changes that markedly affect the cardiovascular health of persons with SCI (Bravo et al. 2004). Adrenergic dysfunction, poor diet, and physical inactivity are thought to play key roles in the elevated risk for CVD in SCI (Warburton et al. 2007b).

As reviewed by Myers et al. (2007) there is consistent information indicating that there is a higher prevalence of CVD in persons with SCI in comparison to ambulatory populations (Groah et al. 2001). For instance, the prevalence rates of symptomatic CVD in SCI have approximated 30%–50% in comparison to 5%–10% in the general able-bodied population (Myers et al. 2007). Moreover, Bauman and colleagues revealed that the prevalence of asymptomatic CVD was 60%–70% in persons with SCI (Bauman et al. 1993; Bauman et al. 1994). It also appears that persons with SCI have increased CVD-related mortality rates and experience mortality at earlier ages in comparison to able-bodied individuals (Whiteneck et al. 1992; DeVivo et al. 1999; Myers et al. 2007). These are alarming statistics, which place a significant burden upon the patient, his/her family, and society as a whole.

Physical inactivity is a major independent risk factor for CVD and premature mortality (Warburton et al. 2006a). Unfortunately, physical inactivity and marked deconditioning are highly prevalent among persons with SCI (Jacobs and Nash 2004). Also, it appears that the ordinary activities of daily living are not adequate to maintain cardiovascular fitness in persons with SCI (Hoffman 1986). It is likely that low levels of physical activity and fitness (as a result of wheelchair dependency) explain (in part) the increased risk for CVD(Myers et al. 2007). Marked inactivity associated with SCI has been associated with lower high-density lipoprotein (HDL) cholesterol (Schmid et al. 2000; Manns et al. 2005); elevated low-density lipoprotein (LDL) cholesterol (Schmid et al. 2000); triglycerides (Schmid et al. 2000; Manns et al. 2005); total cholesterol levels (Schmid et al. 2000); abnormal glucose homeostasis (Elder et al. 2004; Manns et al. 2005); increased adiposity (Elder et al. 2004; Manns et al. 2005); and excessive reductions in aerobic fitness (Schmid et al. 2000; Manns et al. 2005). It is important to note that SCI presents an additional risk for CVD above that seen in able-bodied individuals owing to the marked decrease in physical activity and injury-related changes in metabolic function (Bravo et al. 2004). Moreover, a reduction in cardiovascular fitness may also lead to a vicious cycle of further decline, which results in a reduction in functional capacity and the ability to live an independent lifestyle. Based on the available literature, it is clear that effective exercise interventions are required to slow the progression of multiple risk factors for CVD and other chronic diseases (e.g. obesity, type 2 diabetes) in persons with SCI.

The current chapter summarizes and updates the literature regarding the risk for CVD in persons with SCI. This chapter also evaluates critically the level of evidence regarding the effectiveness of varied forms of exercise rehabilitation in increasing cardiovascular fitness and attenuating the risk for CVD in persons with SCI. Table 7.1 contains a definition of the commonly used terms and/or abbreviations in this chapter (Warburton et al. 2006a).

Table 7.1 Description of Commonly Used Terms

Term	Definition
Spinal Cord Injury (SCI)	• Refers to persons who have sustained a spinal cord injury.
Cardiovascular Disease (CVD)	• Refers to diseases affecting the circulatory system (i.e., heart and/or blood vessels) including acute myocardial infarction, coronary artery disease, arteriosclerosis, heart valve disease, heart failure, high blood pressure, peripheral vascular dysfunction, congenital heart disease, stroke, and arrhythmias.
Physical Activity	• Refers to all leisure and non-leisure body movements resulting in an increased energy output from the resting condition.
Exercise	• Refers to structured and repetitive physical activity designed to maintain or improve physical fitness.
Aerobic Training	• Refers to an exercise program that incorporates activities that are rhythmic in nature, using large muscle groups at moderate intensities for 3 to 5 days per week.
Heart Rate Reserve (HRR)	• Refers to the difference between maximal heart rate (HRmax; predicted or determined directly) and resting HR. The %HRR formula takes into account resting and maximal HR to provide an appropriate target HR (or range) for training. • Training Heart Rate = ((HRmax – HRrest) x 40-85%) + HRrest
MET	• Refers to an estimate of resting metabolic rate while sitting quietly. • 1 MET = 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ or 1 $kcal \cdot kg^{-1} \cdot h^{-1}$
Moderate Intensity Exercise	• Exercise performed at relative intensities of 40-59% HRR, approximately 4-6 METs, or 55-69% of HRmax.
Current General Exercise Recommendation	• Moderate intensity exercise for 20-60 min day on most days of the week.
Activities of Daily Living (ADLs)	• Refers to the activities in which one engages during daily life.
Cardiovascular (Aerobic) Fitness	• Refers to the ability to transport and utilize oxygen during prolonged, strenuous exercise or work. It reflects the combined efficiency of the lungs, heart, vascular system and exercising muscles in the transport and utilization of oxygen.
Maximal Aerobic Power (VO_2max)	• The maximum amount of oxygen that can be transported and utilized by the working muscles. Also, known as maximal oxygen consumption.
Health-related Physical Fitness	• Involves the components of physical fitness that are related to health status including cardiovascular fitness, musculoskeletal fitness, body composition and metabolism.
Quality of Life	• Refers to an overall satisfaction and happiness with life, and includes the facets of physiological, emotional, functional and spiritual well-being.

7.2 The Risk for Cardiovascular Disease in Persons with SCI

The majority of CVD events are the result of atherosclerosis (i.e., narrowing and hardening of the arteries) (Grey et al. 2003). Persons with SCI appear to be particularly susceptible to the development of atherosclerotic disease (Bravo et al. 2004). Researchers have revealed that persons with SCI exhibit a series of risk factors for atherosclerotic disease and thus CVD (as shown in Table 7.2).

A healthy endothelium (interior lining of blood vessels) is essential for the protection against atherosclerosis (Anderson 2003). Relatively limited data exists regarding the vascular health of individuals with SCI (de Groot et al. 2005; Zbogar et al. 2008). However, the majority (if not all) of the risk factors for CVD in persons with SCI will have a significant negative impact upon endothelial function. As such, it would appear that vascular dysfunction is also a central step in the development of CVD in persons with SCI.

Table 7.2 Risk Factors for Cardiovascular Disease in Persons with SCI

Risk Factor	Literature Support
• Abnormal lipoprotein profiles	(Brenes et al. 1986; Dearwater et al. 1986; Bauman et al. 1992b; Krum et al. 1992; Maki et al. 1995; Dallmeijer et al. 1997; Bauman et al. 1998; Bauman et al. 1999a; Bauman et al. 1999b)
• Abnormal glucose homeostasis	(Myllynen et al. 1987; Bauman and Spungen 2001)
• Increased relative adiposity, elevated body fat and/or reduced lean body mass	(Bauman et al. 1999c; Spungen et al. 2003)
• Reduced peripheral vascular function and/or endothelial dysfunction	(Wecht et al. 2000; Wecht et al. 2003; de Groot et al. 2005; Zbogar et al. 2008)
• Increased risk for deep vein thrombosis	(Miranda and Hassouna 2000)
• Abnormal haemostatic and inflammatory markers	(Vaidyanathan et al. 1998; Kahn 1999; Roussi et al. 1999; Kahn et al. 2001; Frost et al. 2005; Lee et al. 2005b)
• Excessive homocysteine	(Bauman et al. 2001)
• Depressed endogenous anabolic hormone levels (e.g. serum testosterone and growth hormone)	(Claus-Walker and Halstead 1982b; Bauman and Spungen 2000)
• Increased activation of the renin-angiotensin-aldosterone system	(Claus-Walker and Halstead 1982a)
• Hypertension	(Lee et al. 2005a)
• Reduced aerobic fitness	(Hoffman 1986)

7.3 Exercise Rehabilitation and Cardiovascular Fitness

Exercise rehabilitation has been shown to be an effective means of attenuating or reversing chronic disease in persons with SCI. Similar to the general able-bodied population (Warburton et al. 2006a), habitual physical activity (beyond activities of daily living) can lead to numerous health benefits that significantly reduce the risk for multiple chronic conditions (in particular CVD) and premature mortality in persons with SCI. However, supporting evidence is relatively low in comparison to the general population and other clinical conditions (e.g., chronic heart failure (Warburton et al. 2006a)).

The research conducted within the field of SCI has examined predominantly the effects of aerobic exercise and/or functional electrical stimulation (FES) training. In the following sections we will review the literature regarding to the effects of varied exercise interventions on the risk for CVD in persons with SCI. Particular attention will be given to the changes in cardiovascular fitness, glucose metabolism, and lipid lipoprotein profiles that occur after training interventions in persons with SCI.

Our search revealed 42 studies examining cardiovascular fitness before and after an exercise intervention. This included investigations related to treadmill training (4 studies; *n* = 47), arm exercise (24 studies; *n* = 316), and FES (21 studies; *n* = 260) training.

7.3.1 Treadmill training

Body-weight–supported treadmill training (BWSTT) is an exercise protocol that has been used to potentially affect a number of domains, including motor recovery, bone density, cardiovascular fitness, respiratory function, as well as quality of life. Traditional BWSTT involves the upright walking on a motor-driven treadmill while a harness (suspended from an overhead pulley system) supports the participant's body weight. Therapists conducting the session determine the magnitude of off-loading of an individual's body weight (Phillips et al. 2004). The treadmill velocity, the amount of body weight supported, and time spent on the treadmill can be individualized (Phillips et al. 2004). Significant resources are often required as the majority of individuals will require one or two assistants to manually help ambulate the lower limbs.

Table 7.3 Effects of Body-weight Sported Treadmill Training on Cardiovascular Fitness and Health

Author Year; Country Score Research Design Total Sample Size	Methods	Outcomes
de Carvalho et al. 2005; Brazil Downs & Black score=17 Pre-Post N=12	**Population:** 12 tetraplegics **Treatment:** Body weight supported treadmill training (30%–50%) with neuromuscular electrical stimulation 20 min/day, 2 days/week for 3 months. **Outcome Measures:** BP and HR.	1. After training, mean systolic blood pressure increased (94 ± 5 mmHg to 100 ± 9 mmHg) at rest and during gait exercise (105 ± 5 to 110 mmHg). 2. There were no significant changes in post-exercise blood pressure after training.
de Carvalho et al. 2006 Brazil Downs & Black score=18 Prospective Controlled Trial N=21	**Population:** 21 male participants (C4 to C8), mean age 32 ± 8 yr. 11 assigned to the gait group and 10 controls. **Treatment:** Body weight supported treadmill training (30%–50%) with neuromuscular electrical stimulation 20 min/day, 2 days/week for 6 months. Control group performed conventional physiotherapy. **Outcome Measures:** BP, oxygen uptake, carbon dioxide production, minute ventilation, and HR.	1. Gait training (six months) resulted in significant increases in oxygen consumption (36%), minute ventilation (31%), and systolic blood pressure (5%) during the gait phase. 2. In the control group, there were significant increases in resting oxygen consumption and carbon dioxide production (31 and 16 %, respectively).
Ditor et al. 2005b; Canada	**Population:** 6 participants (4 male, 2 female), AIS A and B, C4-T12, mean	1. No changes in femoral or carotid artery cross sectional area, blood flow,

Author Year; Country Score Research Design Total Sample Size	Methods	Outcomes
Downs & Black score=14 Pre-post N=6	age 37.7 yrs, mean 6.7 years post-injury, motor complete. **Treatment:** Body weight supported treadmill training, 15 min/day (3 bouts of 5 min), 3 days/week for 4 months. **Outcome Measures:** BP, HR, HR variability, BP variability, arterial diameters and mean blood velocities, and arterial blood flow.	or resistance post-training 2. An improvement in femoral artery compliance. 3. No change in resting BP, mean arterial blood pressure, resting HR or HR and blood pressure variability after training. 4. 3/6 patients had changes in HR and blood pressure variability reflective of increased vagal predominance.
Ditor et al. 2005a; Canada Downs & Black score=14 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 years post-injury. **Treatment:** Progressive, body weight-supported treadmill training, 3 day/week for 6 months. **Outcome Measures:** HR and BP variability, LF/HR ratio (low to high frequency heart spectrum and is indicative of balanced sympathetic/parasympathetic tone and reduced risk for cardiovascular-related mortality).	1. Significant decrease 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 blood pressure variability during an orthostatic challenge (60° head up tilt).

Discussion

Two pre-post studies have been conducted by the same Canadian research group using BWSTT (Ditor et al. 2005a; Ditor et al. 2005b) to determine changes in cardiovascular health. The authors reported that BWSTT did not have substantial group effects on heart rate (HR) and blood pressure in motor-complete subjects but did reveal a significant reduction in resting HR in the study with incomplete tetraplegics. There was also evidence that improvements in HR and blood pressure variability may occur after BWSTT in incomplete SCI and a subset of participants with complete SCI. The authors attributed the change in blood pressure variability to reductions in sympathetic tone to the vasculature. These findings have significant physiological relevance since it indicates that both parasympathetic outflow to the heart (as evaluated by heart rate variability) and sympathetic flow to the vasculature (as evaluated by blood pressure variability) can adapt in response to exercise training. This research group also revealed the potential for improvements in vascular health (e.g., arterial compliance) after BWSTT in individuals with motor-complete SCI. There was no indication of the effects of BWSTT on peak oxygen consumption (VO_2peak).

The mechanisms responsible for the improvement in markers of cardiovascular health and regulation in individuals with incomplete SCI remain to be determined. The authors of the aforementioned studies attributed the training-induced changes in autonomic function to the cardiovascular challenge provided by the upright nature of BSWTT (which potentially could be a sufficient stimulus in individuals with postural hypotension) and the spasticity created during the treadmill training. However, it should also be noted that both weight bearing and the passive movement of the limbs may contribute to the observed changes in these studies.

Two recent investigations (a pre-post study (level 4) and a prospective controlled study (level 2)) from the same research group used partial BWSTT (30%–50%) via neuromuscular electrical stimulation assisted by physiotherapists (de Carvalho and Cliquet 2005; de Carvalho et al. 2006). The first investigation revealed that three months of this form of gait training can result in a significant increase in systolic blood pressure at rest and during gait exercise in tetraplegic males (de Carvalho and Cliquet 2005). In the latter study (de Carvalho et al. 2006) the authors revealed that long-term neuromuscular electrical stimulation gait training (six months) resulted in significant increases in VO_2 (36%), minute ventilation (30.5%), and systolic blood pressure (4.8%) during the gait phase. The authors concluded that treadmill gait training combined with neuromuscular electrical stimulation leads to increased metabolic and cardiorespiratory responses in persons with complete tetraplegia.

In a comparison of trials using BWSTT, an interesting discrepancy arises. For instance, in the work of Ditor et al., there was no change in resting blood pressure after BWSTT in individuals with complete or incomplete SCI (Ditor et al. 2005a; Ditor et al. 2005b). Whereas, the work by de Carvalho and coworkers revealed an increase in resting blood pressure following partial BWSTT (with neuromuscular electrical stimulation) (de Carvalho and Cliquet 2005; de Carvalho et al. 2006). It is not clear why these discrepancies exist, and, as such, further research is clearly warranted.

Conclusion

There is level 4 evidence (Ditor et al. 2005a) that BWSTT improves cardiac autonomic balance in persons with incomplete tetraplegia.

There is level 4 evidence (de Carvalho et al. 2005) that BWSTT can lead to improvements in cardiac autonomic balance in a subset of individuals with motor-complete SCI who respond to ambulation with moderate-to-large increases in heart rate.

Level 4 evidence (Ditor et al. 2005b) indicates that BWSTT can improve arterial compliance in individuals with motor-complete SCI.

There is level 2 evidence (de Carvalho et al. 2006) that neuromuscular electrical stimulation gait training can increase metabolic and cardiorespiratory responses in persons with complete tetraplegia.

> There is limited evidence that BWSTT can improve indicators of cardiovascular health in individuals with complete and incomplete SCI.

7.3.2 Upper extremity exercise

Given the motor loss of the lower limbs following injury, upper extremity exercise is a logical choice. Improving cardiovascular fitness can be challenging using the smaller mass of the arms especially when muscle fatigue can often occur before endurance training targets are met. From our search, we found four RCTs (one high quality (de Groot et al. 2003) and three lower quality trials (Davis et al. 1987; Davis et al. 1991; Hicks et al. 2003)), two prospective controlled (Hooker and Wells 1989; Hjeltnes and Wallberg-Henriksson 1998) and 18 pre-post studies.

Given the large number of studies that have looked at upper extremity exercise, we have tabled only those studies that included a control group consisting of participants with SCI (Table 7.4).

Table 7.4 Effects of upper extremity training on cardiovascular fitness and health.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
	Arm ergometry	
de Groot et al. 2003; Netherlands PEDro = 7 RCT N = 6	**Population:** 4 male, 2 female, C5-L1, AIS A (*n* = 1), B (*n* = 1), C (*n* = 4), age 36 yrs. **Treatment:** Interval training (3-min exercise:2-min rest), 1hr/d, 3d/wk, 8 wks. Randomized to low intensity (50%–60% HRR) or high intensity (70%–80% HRR). **Outcome Measures:** VO_2peak, maximal power output.	1. Greater changes in VO_2peak in the high-intensity (59%) versus low-intensity group (17%).
Davis et al. 1991; Canada PEDro = 4 RCT N = 24	**Population:** 8 spina bifida, 16 traumatic, age 17–42 yrs. **Treatment:** Random assignment to (a) control or 1 of 3 arm ergometry programs 2 d/wk, 24 wks: (1) high-intensity long duration (40 min at 70% VO_2peak), (2) high-intensity short duration (20 min at 70% VO_2peak), and (3) low-intensity short duration (20 min at 50% VO_2peak) training. **Outcome Measures:** Cardiac output, HR, VO_2peak, power output, stroke volume.	1. Training increased VO_2peak in the 3 arm ergometry groups (~21%). 2. There were increases in submaximal stroke volume and cardiac output in the high-intensity long and the low-intensity long training groups. 3. The low-intensity short duration training and control groups exhibited small nonsignificant decreases in stroke volume.
Davis et al. 1987; Canada PEDro = 4 RCT N = 14	**Population:** Sedentary SCI (*n* = 9 exercise group, *n* = 5 control group), age 20–39 yrs. **Treatment:** Arm ergometry, 50%–70% VO_2peak, 20–40 min/d, 3d/wk, 16 wks. **Outcome Measures:** BP, HR, power output, VO_2peak, resting left ventricular dimensions, cardiac function.	1. Significant improvement in VO_2peak (31%) and HR (-9.5%) with training. 2. During isometric handgrip exercise, decreased rate pressure product (20%) and increased stroke volume (12%–16%).
Hjeltnes & Wallberg-Henriksson, 1998; Norway Downs & Black score=16 Prospective controlled trial N = 27	**Population:** Exercise group: 10 tetraplegia, C6-8, 7 AIS A & 3 AIS B; Control: 10 paraplegia, T7-11, all AIS A. **Treatment:** Exercise group: standard rehabilitation + arm ergometry, 30min/d, 3d/wk, 12–16 wks; Control: standard rehabilitation. **Outcome Measures:** power output, cardiac function, HR, VO_2, systolic blood pressure, lactate levels, muscular strength, ability to perform activities of daily living.	1. Tetraplegics increased peak workload (45%) with no change in VO_2peak. 2. Peak workload (45.5%) and VO_2peak (27.7) increased significantly in the paraplegics. 3. No change in peak HR, systolic BP, submaximal exercise stroke volume, or cardiac output in either SCI group.
	Mixed arm and other exercise	
Hicks et al. 2003; Canada PEDro = 5 RCT N = 23	**Population:** 18 tetraplegia and 16 paraplegia, AIS A-D, C4-L1, ages 19–65 yrs. **Treatment:** Exercise: 90–120 min/d, 2d/wk, 9 months of arm ergometry (15–30 min, ~70%VO_2max) and circuit resistance exercise; Control group: bimonthly education session. **Outcome Measures:** muscular strength, power output, HR, quality of life ratings.	1. Power output increased by 118% and 45% after training in the tetraplegic and paraplegic groups, respectively. 2. There were progressive increases in strength over the 9 months of training (range 19%–34%).

Author, Year; Country Score Research Design Sample Size	**Methods**	**Outcomes**
Wheelchair ergometry		
Hooker & Wells 1989; USA Downs & Black score=9 Prospective controlled trial N = 8	**Population:** Low-intensity group *n* = 6, C5-T7; moderate-intensity group *n* = 5, C5-T9. **Treatment:** Wheelchair ergometry 20 min/d, 3 d/wk, 8 wks: low-intensity (50%–60% max HRR) and moderate-intensity (70%–80% max HRR). **Outcome Measures:** HR, power output, blood lactate, VO_2max, Rating of Perceived Exertion (RPE), lipid profiles.	1. The moderate-intensity group had significantly lower post-training submaximal HR, lactate, and RPE but no changes in oxygen consumption. 2. 70% maximal HRR appears to be the beneficial training threshold.

Note: AIS = American Spinal Injury Association; BP = blood pressure; d = day; hr = hour; HR = heart rate; HRR = heart rate reserve; min = minute; RCT = randomized controlled trial; RPE = rating of perceived exertion; SCI = spinal cord injury;wk = week; yr = year.

Discussion

The reported improvements in aerobic capacity after aerobic arm training in SCI are approximately 20%–30%; however, it is not uncommon for improvements in excess of 50% (DiCarlo 1988). The majority of aerobic training investigations have evaluated the effectiveness of moderate (40%–59% heart rate reserve (HRR) or 55%–69% of maximum HR) to vigorous (60%–84% HRR or 70%–89% of maximum HR) intensity exercise. These studies have used arm ergometry, wheelchair ergometry, and swimming-based interventions. Based on the current level of literature, it appears that moderate intensity exercise performed 20–60 minutes per day for at least three days/week for a minimum of six weeks is effective for improving cardiovascular fitness and exercise tolerance in persons with SCI (Level 1 evidence based on one high-quality RCT(de Groot et al. 2003) and several lower quality RCTs). Therefore, the general recommendations provided by agencies such as the Canadian Society for Exercise Physiology are appropriate for improving the cardiovascular fitness of persons with SCI. It is, however, important to note that training intensities may need to be established using a rating of perceived exertion (e.g., RPE) (rather than objective measures of heart rate) in individuals with SCI-induced autonomic denervation of the heart.

An exercise intensity threshold of 70% maximal HRR has been advocated for the attainment of training benefits when a minimal training duration (20 minutes) is the standard (Hooker and Wells 1989; Tordi et al. 2001; Bizzarini et al. 2005). It is also apparent that improvements in exercise capacity and functional status may occur after training without significant changes in VO_2peak, particularly in persons with tetraplegia (Hjeltnes and Wallberg-Henriksson 1998).

Questions remain regarding the primary mechanisms of importance for improvements in aerobic fitness after training. It is unclear whether central (heart and lung) or peripheral (skeletal muscle) adaptations are of key importance. Enhancements have been observed in peripheral muscle function. For instance, investigators have shown intrinsic cellular adaptations in the paralyzed muscle that facilitate oxidative metabolism following BWSTT (Stewart et al. 2004). Only limited investigations, however, have shown an improvement in cardiac function after aerobic exercise training (Davis et al. 1987). It could therefore be argued that peripheral adaptations are of primary importance to the improvement in aerobic capacity after aerobic exercise. However, this statement is somewhat misleading as the majority of studies have not evaluated directly cardiac output during maximal/peak exercise. This is owing to the fact that the assessment of maximal cardiac output during exercise is one of the most difficult procedures in clinical exercise physiology (Warburton et al. 1999a, 1999b). When exercise measures of cardiac function have been taken, improvements in central function have been observed (Davis et al. 1987). Further research examining the primary mechanism(s) of importance for the improved cardiovascular fitness and exercise capacity seen in persons with SCI after aerobic exercise training is warranted. It is also important to highlight that it is often difficult for patients to attain VO_2max during exercise. Moreover, the submaximal prediction of VO_2peak/VO_2max (based on the heart rate response to exercise) is limited owing to the potential impairment in the sympathetic drive to the heart in many persons with SCI. Furthermore, it is often difficult to determine whether the changes in VO_2peak/VO_2max seen after training are related to changes in musculosketelal fitness rather than changes in cardiovascular fitness.

Less is known about the effects of resistance training on cardiovascular fitness. However, the incorporation of resistance training into the treatment of SCI appears to be essential. In fact, muscle weakness and dysfunction are key determinants of pain and functional status in persons with SCI. Previous studies have revealed improvements in VO_2peak/VO_2max (Cooney and Walker 1986; Jacobs et al. 2001), exercise tolerance (Jacobs et al. 2001), and musculoskeletal fitness (Jacobs et al. 2001) after resistance training (e.g., circuit training).

Conclusion

There is level 1 evidence (Davis et al. 1987) that moderate intensity aerobic arm training (performed 20–60 min/day, three days/week for at least 6-8 weeks) is effective in improving the aerobic capacity and exercise tolerance of persons with SCI.

There is level 1 evidence (de Groot et al. 2003) that vigorous intensity (70%–80% HRR) exercise leads to greater improvements in aerobic capacity than moderate intensity (50-60% HRR) exercise.

The relative importance of changes in cardiac function and the ability to extract oxygen at the periphery in persons with SCI after aerobic training remains to be determined.

Tetraplegics and paraplegics can improve their cardiovascular fitness and physical work capacity through aerobic exercise training which are of moderate intensity, performed 20-60 min day, at least three times per week for a minimum of six to eight weeks. Resistance training at a moderate intensity at least two days per week also appears to be appropriate for the rehabilitation of persons with SCI. It remains to be determined the optimal exercise intervention for improving cardiovascular fitness.

7.3.3 Functional electrical stimulation (FES)

Computer-assisted FES during leg cycling has been shown to be an important and practical means of exercising a relatively large muscle mass in persons with SCI (Hooker et al. 1992).

These devices also permit the activation of the skeletal muscle pump during leg cycling. For these reasons, FES training has been widely advocated as an effective treatment strategy for SCI. It is important to note, that the physiological responses to FES training appear to be distinct from arm ergometry training. For instance, arm exercise has been shown to lead to faster VO_2 kinetics (at a constant workload), greater changes in HR, and lower post-exercise blood lactates than FES leg cycling (Barstow et al. 2000).

We identified 9 pre-post (Ragnarsson et al. 1988; Faghri et al. 1992; Hooker et al. 1992; Barstow et al. 1996; Hjeltnes et al. 1997; Mohr et al. 1997; Gerrits et al. 2001; Hopman et al. 2002; Crameri et al. 2004) studies (n = 98) that examined the effectiveness of FES leg cycle ergometry on cardiovascular fitness in SCI. We also identified 6 pre-post (Pollack et al. 1989; Krauss et al. 1993; Mutton et al. 1997; Gurney et al. 1998; Thijssen et al. 2005; Thijssen et al. 2006) investigations (n = 55) that examined hybrid FES (combined leg and arm ergometry) on cardiovascular fitness in SCI. There were a further 6 pre-post (Jacobs et al. 1997; Solomonow et al. 1997; Wheeler et al. 2002; de Groot et al. 2005; Sabatier et al. 2006; Stoner et al. 2007) investigations (n = 107) that examined the effects of other electrically assisted training programs on cardiovascular fitness and health.

7.3.3.1 FES Leg Cycle Ergometry

Table 7.5 Effects of functional electrical stimulation on cardiovascular fitness.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Mohr et al. 1997; Denmark Downs & Black score=14 Pre-post N = 10	**Population:** 6 tetraplegia at C6, 4 paraplegia at T4, all complete, ages 27–45 yrs, 3–23 yrs post-injury. **Treatment:** 1-yr exercise training using an FES cycle ergometer (30 min/d, 3 d/wk). **Outcome Measures:** VO_2max, total work output, blood lactate, muscle properties.	1. 4-fold increase in work output and 12% increase in thigh muscle mass with FES. 2. VO_2max increased 17.5% (6 months) and 19.2% (12 months). 3. Shift toward more fatigue-resistant contractile proteins and a doubling of citric synthase activity.
Ragnarsson et al. 1988; USA Downs & Black score=14 Pre-post N = 19	**Population:** 16 male, 3 females (7 paraplegics T4-T10, 12 tetraplegics C4-C7), ages 19–47 yrs, 2–17 yrs post-injury. **Treatment:** Phase I: quadriceps stimulation with dynamic knee extensions against increasing resistance, 3 d/wk, 4 wks; Phase II: leg-cycle FES, 15-30 min/d, 3 d/wk for 12 wks. **Outcome Measures:** HR, work, BP, and VO_2peak.	1. Most showed an increase in strength and endurance. 2. VO_2peak increased nonsignificantly (14.9%) after training.
Hooker et al. 1992; USA Downs & Black score=13 Pre-post N = 18	**Population:** 17 males, 1 female, 10 tetraplegia (C5-C7), 8 paraplegia (T4-T11), 7 incomplete, age 30.6 yrs, 6.1 yrs post-injury. **Treatment:** FES leg-cycle training 10–30 min/d, 2–3 d/wk, 12–16 wks. **Outcome Measures:** VO_2peak, power output, cardiac output, stroke volume, total peripheral resistance, and HR.	1. Increase in power output (45%), VO_2peak (23%), cardiac output (13%), HR (11%), and a reduction in total peripheral resistance (-14%) during peak FES leg cycle. 2. No changes in stroke volume (6%), mean arterial BP (-5%), or arteriovenous oxygen difference (+10%). 3. No differences during peak arm cranking exercise for any of the cardiovascular variables.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Crameri et al. 2004; Denmark Downs & Black score=12 Pre-post N = 6	**Population:** Paraplegia, complete, C6-T7, ages 26–54 yrs, 3–21 yrs post-injury. **Treatment:** FES training 45 min/d, 3 d/wk, 10 wks. One leg: dynamic cycle ergometry involved bilateral quadriceps and hamstring stimulation; contralateral leg: isometric contractions. **Outcome Measures:** muscle biopsies, capillary-to-fibre ratio, muscle proteins, and oxygenation.	1. The isometric-trained leg showed larger mean increases in force, increase in type 1 fibers, fiber cross-sectional area, capillary-to-fiber ratio, citrate synthase activity, and relative oxygenation after static training in comparison to baseline and the dynamically trained leg.
Hjeltnes et al. 1997; Norway Downs & Black score=12 Pre-post N = 5	**Population:** 5 males, complete chronic lesions, 2 C5, 2 C6, 1 C7, 4 AIS A, 1 AIS A/B, age 35 yrs, 10.2 yrs post-injury. **Treatment:** FES leg cycling, 7 x/wk, 8 wks. **Outcome Measures:** DXA (Body composition), VO_2peak.	1. VO_2peak increased (70%) during FES leg cycling but not during arm exercise. 2. Increase in lean body mass (3.0%) and muscle cross-sectional area (21.3%). 3. Decrease in body fat (6.4%).
Barstow et al. 1996; USA Downs & Black score=12 Pre-post N = 9	**Population:** 9 males, 2 tetraplegia, 7 paraplegia, all AIS A, age 34.4 yrs, 10.1 yrs post-injury. **Treatment:** FES leg-cycle exercise, 30 min (minimum of 24 sessions, 3d/wk). **Outcome Measures:** Work rate, VO_2peak, oxygen pulse.	1. Training significantly increased VO_2peak (10.9%), peak work rate (46.5%), and peak oxygen pulse (12.6%).
Faghri et al. 1992; USA Downs & Black score=12 Pre-post N = 13	**Population:** 6 paraplegics (5 complete), 7 tetraplegics (all incomplete), C4-C7 and T4-T10, age 30.5 yrs, 8 yrs post-injury. **Treatment:** FES leg cycle, 3 d/wk, 12 wks. **Outcome Measures:** BP, power output, HR, VO_2peak, stroke volume, and cardiac output.	1. Increased resting HR and systolic blood pressure in the tetraplegics, while decreased systolic, diastolic, and mean arterial BP in the paraplegics after training. 2. In both groups, decreased submaximal exercise HR and BP and increased stroke volume after training. 3. After training, submaximal cardiac output increased significantly in the paraplegic group.
Gerrits et al. 2001; Netherlands Downs & Black score=14 Pre-post N=9	**Population:** 9 males; Age: mean 39.2 yrs, range 26-61; Level of injury: C4-T6, 4 cervical and 5 thoracic; Time since injury: mean 11.1 yrs, range 2-27; Type of injury: 3 AIS B, 5 AIS A, 1 AIS C **Treatment:** All subjects trained for 6 weeks, 3 d/wk. A training session consisted of a 30-minute FES-LCE exercise. **Outcome Measures:** Longitudinal images and simultaneous velocity spectra of the common carotid and femoral arteries; arterial diameters, peak systolic inflow volumes, mean inflow volume, velocity index	1. Increased work output (300%). 2. No change HR and systolic BP. 3. Six weeks of FES-LCE training resulted in an increase in diameter of the femoral artery (pre-training 7.5±1.5 mm vs. post-raining 8.1±1.5 mm) whereas the diameter of the common carotid artery remained unchanged. 4. Velocity index, an indicator for peripheral resistance, decreased from 1.24±0.11 to 1.14±0.12 in the femoral artery; unchanged in common carotid 5. Larger resting inflow volumes of the femoral artery were found after training as peak systolic inflow increased from 1330±550 mL/min to 1710±490 mL/min and mean

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
		inflow volume increased from 270±120 mL/min to 370±160 mL/min. 6. After training, hyperemic response is augmented.
Hopman et al. 2002; The Netherlands Downs & Black score=16 Pre-post N=9	**Population:** 9 males; Level of injury: thoracic and cervical; Type of injury: AIS A; Time since injury: range 1-22 years. Mean age (including 2 other subjects not included in this part of the study) = 40.7±7.2 yrs. **Treatment:** Cycle training was performed by using a computer-controlled leg cycle ergometer with electrodes placed over hamstring, gluteal, and quadriceps muscles. Subjects trained for 30 minutes, 3x/week for 6 wks. **Outcome Measures:** Mean arterial pressure, resting blood flow in femoral artery	1. Mean arterial pressure was similar after training compared with values before training. 2. Larger resting blood flow in the femoral artery was found after training. Peak systolic blood flow increased from 1330±550 to 1710±490 mL/min and mean blood flow increased from 270±120 to 370±160 mL/min. 3. Calculated vascular resistance decreased by 30% after 6 weeks of training.

Note: AIS = American Spinal Injury Association; BP = blood pressure; d = day; FES = functional electrical stimulation; hr = hour; HR = heart rate; min = minute; wk = week; yr = year.

7.3.3.2 Hybrid FES (Combined Leg and Arm Ergometry)

Table 7.6 Effects of hybrid FES training on cardiovascular fitness and health.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Thijssen et al. 2005; Netherlands Downs & Black score=14 Pre-post N = 10	**Population:** 9 males, 1 female, T1-T12, 9 complete, age 39.2 yrs, 1–20 yrs post-injury. **Treatment:** Simultaneous FES cycle ergometry and arm ergometry, 30 min/d, 2–3 d/wk, 4 wks. **Outcome Measures:** VO$_2$peak, blood flow and vascular resistance, and echo Doppler (diameter and flow-mediated dilation (FMD) after 13 min of ischemia).	1. Training resulted in increased thigh resting (43.5%) and peak blood flow (17.1%), decreased thigh resting vascular resistance (31.8%), and increased femoral artery diameter. 2. After training, there was an increase in maximal workload (6.8%), VO$_2$peak (6.1%), and resistance to fatigue.
Thijssen et al. 2006; Netherlands Downs & Black score=20 Pre-post N = 9	**Population:** 8 males, 1 female, C5-T12, 8 complete AIS A, 1 incomplete AIS C, age 39 yrs, 11 yrs post-injury. **Treatment:** Simultaneous FES cycle ergometry and arm ergometry, 25 min/d, 2 d/wk, 6 wks followed by 6-wks detraining. **Outcome Measures:** Blood flow of thigh, diameter of the femoral artery and flow-mediated dilation.	1. After 2 wks of training, there was a significant increase in baseline and peak blood flow, an increase in femoral artery diameter, and a decrease in femoral artery flow-mediated dilation (FMD). 2. Detraining lead to a reversal of baseline and peak thigh blood flow, vascular resistance, and femoral diameter. 3. Detraining did not restore femoral artery FMD.
Gurney et al. 1998; USA Downs & Black score=12	**Population:** All male, C4-T10, 4 paraplegia, 2 tetraplegia, ages 23–41	1. Increased VO$_2$peak (81.7%) and workload with FES leg cycle.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Pre-post N = 6	yrs, 5–24 yrs post-injury. **Treatment:** Phase I: FES leg cycle, 3 d/wk, 6 wks; Phase II: FES leg cycle with simultaneous, voluntary arm ergometry, 3 d/wk, 6 wks; Phase III: 8-wks detraining. **Outcome Measures:** VO_2peak, submaximal and maximal HR.	2. After an 8-wk detraining period, peak workload returned to baseline; VO_2peak remained higher.
Mutton et al. 1997; USA Downs & Black score=12 Pre-post N = 11	**Population:** All male, complete AIS A, C5-6 to T12-L1, age 35.6 yrs, 9.7 yrs post-injury. **Treatment:** 3 phases of exercise training (FES leg-cycle ergometry). Phase I progressive FES leg-cycle exercise (FES-LCE) to 30 min of exercise; Phase II ~35 sessions of FES-LCE; and Phase III ~41 sessions (30 min each) of combined FES-LCE and arm ergometry. **Outcome Measures:** VO_2peak and submaximal physiological parameters (VO_2, HR, blood lactate).	1. In response to FES-LCE training both VO_2peak and peak work rate during graded FES leg exercise (but not graded arm ergometry) testing improved. 2. With hybrid training, VO_2peak (13%) and peak power output (28%) were increased during graded hybrid testing, but not during graded arm or graded FES leg testing alone.
Krauss et al. 1993; USA Downs & Black score=12 Pre-post N = 8	**Population:** 7 male, 1 female, 7 paraplegia, 1 tetraplegia, age 32 yrs, 13 yrs post-injury. **Treatment:** 2 phase program. Phase I: FES leg cycling 3 d/wk, 6 wks; Phase II: FES leg cycle plus simultaneous arm ergometry for 6 wks. **Outcome Measures:** VO_2peak, HR, workload, peak lactate.	1. After Phase I, arm ergometer VO_2peak (21.9%) and FES leg ergometer VO_2peak (62.7%) increased. 2. After Phase II, the hybrid exercise VO_2peak increased 13.7%. 3. Peak HR only increased with training during FES leg ergometry.
Pollack et al. 1989; USA Downs & Black score=11 Pre-post N = 11	**Population:** 7 male and 4 female, C4-C6 and T2-T6, complete motor lesions, ages 18–54 yrs, 6–132 months post-injury. **Treatment:** 3 phase program over 13–28 wks. Phase I: quadriceps stimulation (knee extension); Phase II: FES leg cycle with 0–1 kp resistance; Phase III: loaded FES leg cycle, 3 d/wk, 3 wks. **Outcome Measures:** BP, HR, oxygen consumption.	1. There were significant increases in endurance time (288%), VO_2peak (95.9%), and HR (16.8%) and decreases in diastolic BP (31.5%) with training.

7.3.3.3 Other Electrically-Assisted Training Programs

Table 7.7 Effects of other electrically assisted training programs on cardiovascular fitness and health.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Other forms of electrically assisted training		

Author, Year; Country Score Research Design Sample Size	**Methods**	**Outcomes**
Wheeler et al. 2002; Canada Downs & Black score=17 Pre-post N = 6	**Population:** C7-T12, 5 AIS A, 1 AIS C, age 42.5 yrs, 13.8 yrs post-injury. **Treatment:** FES (quadriceps) with arm rowing (70%–75%VO_2peak) 30 min/d, 3 d/wk, 12 wks. **Outcome Measures:** Total rowing distance, VO_2peak, and peak oxygen pulse.	1. Training resulted in significant increases in rowing distance (25%), VO_2peak (11.2%), and peak oxygen pulse (11.4%).
Sabatier et al. 2006; USA Downs & Black score=15 Pre-post N = 5	**Population:** All male, complete AIS A, C5-T10, age 35.6 yrs, 13.4 yrs post-injury. **Treatment:** Home-based electrical stimulation 2 d/wk, 18 wks. **Outcome Measures:** Femoral artery diameter and blood flow, weight lifted, muscle mass, and muscle fatigue.	1. Training resulted in significant increases in weight lifted and muscle mass and a decrease 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.
Solomonow et al. 1997; USA Downs & Black score=13 Pre-post N = 70	**Population:** All paraplegia, no other details given. **Treatment:** Reciprocating gait orthosis (RGO) 3 hr/wk, 14 wks. **Outcome Measures:** Cardiac output, stroke volume, vital capacity, knee extensor torque, and heart rate at the end of a 30 m walk.	1. There was a non-significant increase in cardiac output (7.1%) and stroke volume (5.0%) after training. 2. There was a significant increase in knee extensor torque (78.2%).
de Groot et al. 2005; Netherlands Downs & Black score=10 Pre-post N = 6	**Population:** SCI: 3 male, 3 female, T4-L2, all complete AIS A/B, age 43 yrs, 14.5 yrs post-injury; Controls: 8 able-bodied individuals (4 male, 4 female), age 41 yrs. **Treatment:** Unilateral surface stimulation of the quadricep, tibial anterior, and gastrocnemius muscles, 30 min/d, daily, 4 wks. **Outcome Measures:** Leg circumference, total limb volume, resting mean red blood cell velocity and vessel diameter and blood pressure.	1. An increase in arterial compliance and a decrease in the flow-mediated dilation in the femoral artery of the trained leg, with no changes in these vascular parameters in the femoral artery of the untrained leg, the carotid artery, and the brachial artery. 2. There were no significant training-related changes in resting vessel diameter, blood flow, or shear rate in the femoral, carotid, and brachial arteries.
Jacobs et al. 1997; USA Downs & Black score=14 Pre-post N=15	**Population:** 12 males and 3 females; Age: mean 28.2±6.8 yrs, range 21.1-45.2 yrs; Time since injury: mean 3.7±3.0 yrs, range 7-8.8 yrs; Type of injury: all AIS A paraplegia; Level of injury: T4-T11 **Treatment:** 32 sessions of functional neuromuscular stimulation ambulation training using a 6-channel system (Parastep ® 1). Subjects trained 3 days/week. Typically, three walking trials were completed during each training session. Subjects chose ambulation pace and duration. **Outcome measures:** HR, peak VO_2	1. Heart rate was lower throughout sub-peak levels of arm ergometry after the ambulation training. 2. Peak VO_2 increased from 20.02±3.27 mL/kg/min to 23.01±3.61 mL/kg/min post-training.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
Stoner et al. 2007; USA Downs & Black score=16 Pre-post N=5	**Population:** 5 males; Age: mean 35.6±4.9 yrs; Level of injury: range C5-T10; Time since injury: mean 13.4±6.5 yrs; Type of injury: AIS A. **Treatment:** NMES-induced resistance training; the quadriceps femoris muscle group of both legs were trained 2x/week with 4x10 repetitions of unilateral, dynamic knee extensions for 18 weeks. **Outcomes measures:** FMD and resting diameter and arterial range of the posterior tibial artery.	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.

Note: AIS = American Spinal Injury Association; BP = blood pressure; d = day; FES = functional electrical stimulation; HR = heart rate; min = minute; wk = week; yr = year; peak VO_2 = peak oxygen consumption.

Discussion

There is a growing body of literature indicating that FES exercise training is an effective way of improving cardiovascular health, peak power output, and exercise tolerance/capacity in persons with SCI (Table 7.5). These studies generally employ a cycling motion, although rowing and bipedal ambulation have also been evaluated. It appears that moderate-to-vigorous intensity FES training (relative to baseline capacity) may be effective in enhancing cardiovascular fitness in persons with SCI. The majority of the investigations are pre-post designs (level 4) with investigators reporting marked changes in VO_2max or VO_2peak after FES training. Similar to aerobic training, 20%–40% changes in aerobic capacity are often observed after FES training. However, improvements in excess of 70% are not uncommon.(Faghri et al. 1992)

Investigations with FES training have also shown an improvement in musculoskeletal fitness. Similar to arm exercise training, limited investigations have shown an improvement in cardiac function after FES training. A recent investigation has also revealed that the degree of muscular adaptation that can be achieved via FES exercise is dependent upon the load that is applied to the paralyzed muscle (Crameri et al. 2004).

Researchers have also shown that hybrid exercise training (FES leg cycling combined with arm ergometry) may elicit greater changes in peak work rates and VO_2peak/VO_2max than FES leg-cycling exercise alone (Krauss et al. 1993; Mutton et al. 1997). Moreover, it appears that the physiological adaptations to combined FES leg cycling and arm ergometry training are partially maintained after eight weeks of detraining (Gurney et al. 1998). Other interventions (Table 7.7) that make use of hybrid FES training have also been shown to improve the exercise capacity and cardiovascular health of persons with SCI. It would appear that the potential adaptations with hybrid exercise may be greater than FES alone; however, further research is required to test this hypothesis.

A series of intrinsic muscle adaptations can also occur after FES training that enhance the ability for oxidative metabolism at the cellular level, which in turn facilitate improved endurance, exercise tolerance and functional capacity. Key intrinsic muscle adaptations that have been observed include an increase in the proportion of type 1 fibres, an enhancement in cross-sectional fibre area, an increase in capillary-to-fibre ratio, a shift towards more fatigue resistant contractile proteins, and an increase in citrate synthase activity. Given the importance of musculoskeletal fitness for health and functional status (Warburton et al. 2001b; 2001a;

Warburton et al. 2006b), further research is clearly warranted with persons with SCI. Accordingly, randomized, controlled exercise interventions (both arm and/or FES training) that evaluate concurrent changes in musculoskeletal fitness and health status are particularly needed.

Conclusion

There is level 4 evidence from multiple pre-post studies that FES training performed for a minimum of three days per week for two months may be effective for improving musculoskeletal fitness, the oxidative potential of muscle, exercise tolerance, and cardiovascular fitness.

There is level 4 evidence from multiple pre-post studies that FES training may be effective in improving exercise cardiac function in persons with SCI.

> Interventions that involve FES training a minimum of 3 days per week for 2 months may improve muscular endurance, oxidative metabolism, exercise tolerance, and cardiovascular fitness.

7.3.4 Other Forms of Exercise Interventions

Various forms of exercise interventions have been used in an attempt to improve the health status of persons with SCI (Hopman et al. 1996; Duran et al. 2001; Ter Woerds et al. 2006). The forms of potential interventions are numerous and varied. As such, it is difficult to systematically review the literature regarding alternative forms of exercise interventions for SCI. Therefore, we have provided a brief summary of studies that have incorporated non-traditional forms of rehabilitation in SCI (Table 7.8).

Table 7.8 Other Forms of Exercise Interventions.

Author Year; Country Score Research Design Sample Size	Methods	Outcomes
Quad Rugby		
Hopman et al. 1996; The Netherlands Downs & Black score=14 Pre-post N=21	**Population:** Subjects divided into 3 groups according to their fitness levels. All subjects had a cervical SCI (C4 to C8), tetraplegia. (1) Trained group (T) (n=8): All males; Age: 32.7±12.7; Time since injury: 8.1±10.3; Type of injury: 4 incomplete, 4 complete (2) Untrained group (U) (n=7): 6 males and 1 female; Age: 26.6±6.9; Time since injury: 6.6±5.2; Type of injury: All complete (3) Sedentary group(S) (n=6): 4 males and 2 females; Age: 36.5±10.4; Time since injury: 9.1±3.9; Type of injury: All but one with complete lesion **Treatment:** Untrained and trained group trained once a week and played 2 games/month for 6 months.	1. No significant differences were found in either absolute or relative changes in the physiological responses to arm exercise for submaximal and maximal exercise over 3 or 6 months in U, T, and S groups.

Author Year; Country Score Research Design Sample Size	Methods	Outcomes
	Training consisted of endurance, sprint, and skill training. The U trained 42.2 min and T 21.3 min above 60% HR_{res} during training. **Outcome Measures:** Physiological responses to maximal and submaximal arm-cranking exercise.	
	Passive Exercises	
Ter Woerds et al. 2006; The Netherlands Downs & Black score=13 Prospective controlled trial N=16	**Population:** (1) SCI group: 8 males; Age: 35±8.4; Level of injury: 7 thoracic, 1 thoracic-lumbar, range T2-L1; Type of injury: 6 AIS A, 2 AIS B; Time since injury: 8.3±6.1; Hours of exercise/week: 5.7±3.9. (2) Control group: 8 males; Age: 26±4.5; Hours of exercise/week: 4.7±2.3. **Treatment:** Each subject successively underwent 2 interventions, passive leg movements (10 minutes) and passive cycling (20 minutes). **Outcomes measures:** Leg blood flow, mean red blood cell velocity in and diameter of common femoral artery, leg vascular resistance, MAP, total peripheral resistance	1. Blood flow, vascular resistance, and blood pressure in the common femoral artery did not change during or after 2 different passive exercise interventions in the subjects with SCI or the control subjects.
	Wheelchair skills + weight training	
Durán et al. 2001; Columbia Downs & Black score=21 Case series N=13	**Population:** 12 males and 1 female; Age: 26.3±8.3; Level of injury: All thoracic, T3-T12; Time since injury: 2-120 months; Type of injury: 11 AIS A, 1 AIS B, 1 AIS C. **Treatment:** The program lasted for 16 weeks, with a frequency of 3 sessions (120 minutes) per week. Mobility activities, aerobic resistance, strength, coordination, recreation, and relaxation were combined. The specific aerobic program lasted 11 weeks, including a 4-week adaptation and 1-week enhancement period. Progressively led to 40 minutes of aerobic training at 40% to 60% HR reserve. **Outcome measures:** FIM (functional independence measure), arm crank exercise test, lipid levels	1. Pre-training FIM scores mean 106±7 vs. 113±7 post-training. Highest increase occurred in mobility. 2. Lipid profiles and average resting heart rate did not change. 3. Maximum resistance achieved during arm exercise test increased from 90±24 watts to 110±26 watts. 4. HR at 6 minutes after exercise test decreased from 115±19 bpm to 108±19 bpm.

Discussion

The evidence supporting non-traditional forms of exercise interventions in SCI is not clear. This is to be expected given the varied training methodologies that can be employed. The lack of concrete information should not however dissuade researchers from considering non-traditional rehabilitation models when dealing with SCI. It is clear that novel models of exercise rehabilitation are warranted and desired in the rehabilitation of SCI. Some modalities of exercise that have been applied with success in able-bodied individuals (such as interactive video games (Warburton et al. 2007a)) or other clinical populations (e.g. interval training (Warburton et al. 2005)) may hold great promise for persons with SCI. As with early research with FES, it is essential that researchers demonstrate innovative thinking that is based upon a strong theoretical foundation.

7.4 Glucose homeostasis

Glucose intolerance and decreased insulin sensitivity are independent risk factors for CVD (Hurley and Hagberg 1998). Abnormal glucose homeostasis is associated with worsened lipid lipoprotein profiles and an increased risk for the development of hypertension and type 2 diabetes (Hurley and Hagberg 1998; Warburton et al. 2001b; 2001a). It is well-established that habitual physical activity is an effective primary preventative strategy against insulin resistance and type 2 diabetes in the general population.(Warburton et al. 2006b). Although comparatively less information is available for SCI, it appears that exercise training programs are effective in improving glucose homeostasis (Hjeltnes et al. 1998; Chilibeck et al. 1999; de Groot et al. 2003; Phillips et al. 2004; Mahoney et al. 2005). Key terms used when assessing glucose homeostasis are provided in Table 7.9.

Table 7.9 Glucose homeostasis key terms.

Oral Glucose Tolerance Test (OGTT)	• Involves the ingestion of glucose and the subsequent serial blood analysis of glucose levels to determine the rate of blood glucose removal. Common test used in the diagnosis of diabetes.
Insulin Sensitivity	• Refers to the sensitivity of target cells (muscle, hepatic cells and adipose) to insulin.
Blood Glucose	• Refers to blood levels of glucose (a simple sugar, carbohydrate). High fasting blood glucose levels reflects pre-diabetic or diabetic conditions.
Blood Insulin	• Refers to blood levels of insulin (a hormone that regulates carbohydrate metabolism).
Glucose Transporters (GLUT-4)	• Glucose transporters are important membrane proteins that facilitate the transport of glucose through the cellular membrane. GLUT4 is an insulin-regulated glucose transporter located in adipose and muscle tissues.
Glycogen Synthase	• Enzyme involved in the synthesis of glycogen from glucose.
Hexokinase	• An enzyme that acts during carbohydrate metabolism. In the first step of glycolysis, hexokinase phosphorylates (transfers phosphate from ATP) glucose to prepare it for subsequent breakdown for use in energy production.
Citrate Synthase	• Citrate synthase is an important enzyme in the Citric Acid Cycle (Krebs cycle).
Phosphofructokinase	• Phosphofructokinase (PFK) is an important regulatory enzyme of glycolysis.

Table 7.10 Effects of exercise training on glucose metabolism in persons with spinal cord injury.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
de Groot et al. 2003; The Netherlands PEDro = 7 RCT	**Population:** 4 male, 2 female, C5-L1, AIS A (*n* = 1), B (*n* = 1), and C (*n* = 4), age 36 yrs, 116 d post-injury.	1. There was a significant difference in insulin sensitivity between groups, with a nonsignificant decline in the high-

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes
N = 6	**Treatment:** 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.	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* = .02).
Mahoney et al. 2005; USA Downs & Black score=17 Pre-post N = 5	**Population:** 5 males, complete SCI, C5-T10, AIS grade A, age 35.6 yrs, 13.4 yrs post-injury. **Treatment**: Home-based neuromuscular electric stimulation-induced resistance exercise training, 2 d/wk, 12 wks. **Outcome Measures:** quadriceps femoris muscle cross-sectional area, plasma glucose, insulin.	1. All participants had normal fasting glucose levels before and after training. 2. There were no significant changes in blood glucose or insulin with training. However, there was a trend towards reduced plasma glucose levels (*p* = .074).
Hjeltnes et al. 1998; Sweden Downs & Black score=13 Pre-post N = 5	**Population:** 5 males, C5-C7, all complete AIS A, age 35 yrs, 10 yrs post-injury. **Treatment:** Electrically stimulated leg cycling exercise, 7 d/wk, 8 wks. **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 increased by 33%. There was a 2.1-fold increase in insulin-stimulated glucose transport. 2. Training led to marked increases in protein expression of GLUT4 (glucose transporter) (378%), glycogen synthase (526%), and hexokinase II (204%) in the vastus lateralis muscle. 3. Hexokinase II activity increased 25% after training.
Phillips et al. 2004; Canada Downs & Black score=12 Pre-post N = 9	**Population:** 8 male, 1 female, incomplete AIS C, C4-T12, 8.1 yrs post-injury. **Treatment:** Body-weight–supported treadmill walking, 3 d/wk, 6 months. **Outcome Measures:** whole-body dual-energy X-ray absorptiometry, GLUT4 protein abundance, hexokinase activity, oral glucose tolerance tests, glucose oxidation, CO_2 breath analysis.	1. Reduction in the area under the curve for glucose (-15%) and insulin (-33%). 2. The oxidation of exogenous (ingested) glucose and endogenous (liver) glucose increased (68% and 36.8%, respectively) after training. 3. Training resulted in increased muscle glycogen, GLUT-4 content (glucose transporter) (126%), and hexokinase II enzyme activity (49%).
Jeon et al. 2002; Canada Downs & Black score=11 Pre-post N = 7	**Population:** 5 male, 2 female, motor complete, C5-T10, ages 30-53 yrs, 3–40 yrs post-injury. **Treatment:** 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 8 wk of training. 2. Glucose utilization was higher for all 3 participants and insulin sensitivity was higher for 2 of the 3 participants during posttraining 2-hr clamp test.
Mohr et al. 2001; Denmark Downs & Black score=10 Pre-post N = 10	**Population:** 8 male, 2 female, 6 tetraplegia, 4 paraplegia, C6-T4, age 35 yrs, 12 yrs post-injury. **Treatment:** FES cycling, 30 min/d, 3 d/wk, 12 months; 7 participants	1. Insulin-stimulated glucose uptake rates increased after intensive training. 2. With the reduction in training, insulin sensitivity decreased to a

Author, Year; Country **Score** **Research Design** **Sample Size**	**Methods**	**Outcomes**
	completed an additional 6 months (1 d/wk). **Outcome Measures:** insulin-stimulated glucose uptake, oral glucose tolerance test (OGTT), GLUT 4 glucose transporter protein.	similar level as before training. GLUT-4 increased by 105% after intense training and decreased again with the training reduction. The participants had impaired glucose tolerance before and after training, and neither glucose tolerance nor insulin responses to OGTT were significantly altered by training.
Chilibeck et al. 1999; Canada Downs & Black score=10 Pre-post N = 5	**Population:** 4 male, 1 female, motor complete C5-T8, ages 31–50 yrs, 3–25 yrs post-injury. **Treatment:** FES leg-cycle ergometry training, 30 min/d, 3 d/wk, 8 wks. **Outcome Measures:** glucose transporters (GLUT-4, GLUT-1), oral glucose tolerance test, citrate synthase.	1. Training resulted in increases in GLUT-1 (52%) and GLUT-4 (72%). 2. There was a training-induced increase in citrate synthase activity (56%) and an improvement in the insulin sensitivity index as determined from oral glucose tolerance test.

Note: AIS = American Spinal Injury Association; d = day; FES = functional electrical stimulation; HRR = heart rate reserve; min = minute; OGTT = oral glucose tolerance test; RCT = randomized controlled trial; SCI = spinal cord injury; wk = week.

Discussion

The majority of the data is from experimental non-RCT trials. A search of the literature revealed seven investigations (*n* = 47). This included one RCT (de Groot et al. 2003) and six experimental non-RCT (pre-post) trials(Hjeltnes et al. 1998; Chilibeck et al. 1999; Mohr et al. 2001; Jeon et al. 2002; Phillips et al. 2004; Mahoney et al. 2005). The single RCT involved the randomization to two different forms of exercise, and, as such, an exercise condition served as the control (Table 7.10). The majority (five) of these trials examined the effectiveness of FES training.

Similar to other studies in the field of SCI research, this area of investigation is limited by the lack of quality RCTs. Moreover, the majority of the research relates to the effects of FES training. Limited work has been conducted using aerobic and/or resistance exercise training. As a whole, however, these studies are consistent and reveal several important findings. For instance, the improvements in glucose homeostasis may be the result of increased lean body mass (and associated changes in insulin sensitivity) and increased expression of GLUT-4, glycogen synthase, and hexokinase in exercised muscle.

Consistent with findings in able-bodied individuals (Warburton et al. 2001b; 2001a), the improvement in glucose homeostasis after exercise interventions (e.g., aerobic training or FES) does not appear to be related solely to decreases in body adiposity and/or increases in VO_2max. This is due to the fact that significant improvements in glucose homeostasis can occur with minor changes in body composition and/or aerobic fitness.

It is also important to note that there appears to be a minimal volume of exercise required for improvements in glucose homeostasis. For instance, Mohr et al. (2001) revealed that a reduction of FES training was not sufficient to maintain the beneficial changes in insulin sensitivity and GLUT-4 protein observed during a three days/week FES training program.

Conclusion

There is level 1 evidence from 1 RCT (de Groot et al. 2003) and multiple level 4 studies (Chillibeck et al. 1999; Mohr et al. 2001; Jeon et al. 2002) that both aerobic and FES training (approximately 20–30 min/day, three days/week for eight weeks or more) are effective in improving glucose homeostasis in persons with SCI.

There is level 4 evidence from multiple pre-post studies that the changes in glucose homeostasis after aerobic or FES training are clinically significant for the prevention and/or treatment of type 2 diabetes.

> Aerobic and FES exercise training may lead to clinically significant improvements in glucose homeostasis in persons with SCI. Preliminary evidence indicates that a minimum of 30 min of moderate intensity training on 3 days per week is required to achieve and/or maintain the benefits from exercise training.

7.5 Lipid lipoprotein profiles

Abnormal lipid lipoprotein profiles have been associated with an increased risk for CVD (Hurley and Hagberg 1998; Warburton et al. 2001b; 2001a; Warburton et al. 2006a; 2006b). Several studies have revealed worsened lipid lipoprotein profiles in persons with SCI (Brenes et al. 1986; Dearwater et al. 1986; Bauman et al. 1992a; Krum et al. 1992; Maki et al. 1995; Dallmeijer et al. 1997). Routine physical activity has been shown to enhance lipid lipoprotein profiles by reducing triglycerides (TG), increasing HDL, and lowering LDL/HDL in the general population.(Warburton et al. 2001b; 2001a; Warburton et al. 2006a) Although limited, similar findings have been observed in persons with SCI (Hooker and Wells 1989; Solomonow et al. 1997; Nash et al. 2001; de Groot et al. 2003; Stewart et al. 2004; El-Sayed and Younesian 2005) (Table 7.12). Table 7.11 describes the common lipid lipoprotein measurements.

Table 7.11 Lipid Lipoprotein Profiles

Low-density lipoprotein (LDL)	• Lipid protein complex that transports cholesterol from the liver to other tissues within the body. LDL is often referred to as the "bad" cholesterol. LDL levels above 160 mg/dL (4.1 mmol/L) are considered to be high.
High-density lipoprotein (HDL)	• Lipid protein complex that transports cholesterol from the tissues to the liver for excretion and re-utilization. HDL is often referred to as the "good" cholesterol. HDL levels of <40 mg/dL (<1.03 mmol/L) are associated with an increased risk for CVD.
Total cholesterol (TC)	• Total amount of all cholesterol in the blood (↑TC related to ↑risk for CVD)
Triglycerides (TG)	• High energy fatty acids which form much of the fat stored by the body

Table 7.12. Effects of exercise training on lipid lipoprotein profiles in persons with spinal cord injury.

Author, Year; Country Score Research Design Sample Size	Methods	Outcomes

Author, Year; Country Score Research Design Sample Size	**Methods**	**Outcomes**
de Groot et al. 2003; Netherlands PEDro = 7 RCT N = 6	**Population:** 4 male, 2 female, C5-L1, AIS A (*n* = 1), B (*n* = 1), and C (*n* = 4), age 36 yrs, 116 d post-injury. **Treatment:** 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:** lipid profiles including total cholesterol (TC), HDL, LDL, triglycerides (TG).	1. The TC/HDL and triglycerides decreased significantly more in the high-intensity group.
El-Sayed et al. 2005; UK Downs & Black score=13 Pre-post N = 12	**Population:** 5 SCI, lesion below T10, age 32 yrs; 7 AB controls, age 31 yrs. **Treatment:** Arm ergometry, 30 min/d (60%–65%VO_2peak), 3 d/wk, 12 wks. **Outcome Measures:** VO_2peak, peak HR, peak workload, TC, triglycerides, HDL.	1. Training improved HDL but did not alter TC or triglycerides.
Solomonow et al. 1997; USA D&B = 13 Pre-post N = 70/33	**Population:** All paraplegia, no other details given. **Treatment:** Reciprocating gait orthosis powered with electrical muscle stimulation, 3 hr/wk, 14 wks. **Outcome Measures:** cholesterol, LDL, HDL	1. There were significant reductions in total cholesterol, LDL, LDL/HDL, and TC/HDL in 8 patients with initially high total cholesterol levels (>200 mg/dL).
Nash et al. 2001; USA Downs & Black score=11 Pre-post N=5	**Population:** 5 males, complete lesions T6-L1, age 37.8 yrs, 4.8 yrs post-injury. **Treatment:** Circuit resistance training (50%–60%1 repetition maximum), 3 d/wk, 12 wks. **Outcome Measures:** VO_2peak, time to fatigue, TC, triglycerides, HDL, LDL.	1. There were significant decreases in LDL, LDL/HDL, and TC/HDL after training.
Stewart et al. 2004; Canada Downs & Black score=10 Pre-post N = 9	**Population:** 8 male, 1 female, incomplete AIS C, C4-T12, 8.1 yrs post-injury. **Treatment:** 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%).
Hooker & Wells, 1989; USA Downs & Black score=9 Prospective controlled trial N = 8	**Population:** Low-intensity group: *n* = 6, 3 male, 3 female, C5-T10, age 26–36 yrs, 3 months to 19 yrs post-injury; moderate-intensity group: *n* = 5, 3 male, 2 female, C5-T9, age 23–30 yrs, 2–19 yrs post-injury. **Treatment:** Wheelchair ergometry 20 min/d, 3 d/wk, 8 wks: low-intensity (50%–60% max HRR) and moderate intensity (70%–80% max HRR). **Outcome Measures:** total cholesterol (TC), triglycerides, HDL, LDL.	1. No change in lipid levels in low-intensity group. 2. Significant increases in HDL and decreases in triglycerides, LDL, and the TC/HDL ratio in the moderate intensity group.

Note: AIS = American Spinal Injury Association; d = day; HDL = high-density lipoprotein; hr = hour; HRR = heart rate reserve; LDL = low-density lipoprotein; min = minute; RCT = randomized controlled trial; TC = total cholesterol; wk = week; yr = year.

Discussion

The information regarding the effects of exercise training on lipid lipoprotein profile is derived from one high-quality RCT (level 1),(de Groot et al. 2003) one nonrandomized, prospective controlled trial (level 2),(Hooker and Wells 1989) and several level 4 studies (Solomonow et al. 1997; Nash et al. 2001; Stewart et al. 2004; El-Sayed and Younesian 2005) (*N* = 110). The majority of the investigations examined a form of aerobic training (either arm ergometry or assisted treadmill walking). Another investigation examined the effects of reciprocating gait orthosis powered with electrical muscle stimulation.

These findings provide level 1 evidence (based on one high-quality RCT and several lower quality studies) for the role of exercise in the reduction of atherogenic lipid lipoprotein profiles and the reduction of the risk for CVD in persons with SCI. It appears that a minimal threshold of training exists for changes in lipoprotein profile. For instance, authors have reported that 70% of maximal HRR (for at least 20 min/day, three days/week for eight weeks) is the threshold necessary to achieve significant improvements in lipid lipoprotein profiles. Future research is warranted, however, to quantify the effects of varying forms of exercise (including aerobic exercise, resistance exercise, and FES) on lipid lipoprotein profiles in persons with SCI.

Conclusion

There is level 1 evidence from 1 high quality RCT (de Groot et al. 2003) to suggest that aerobic exercise training programs (performed at a moderate to vigorous intensity 20-30 min/day, 3 days per week for 8 weeks) are effective in improving the lipid lipoprotein profiles of persons with SCI.

Preliminary evidence (level 4; Solomonow et al. 1997) also indicates that the use of a reciprocating gait orthosis with FES training (3 hours/week, for 14 weeks) may improve lipid lipoprotein profiles in SCI.

Aerobic and FES exercise training may lead to improvements in lipid lipoprotein profile that are clinically relevant for the at risk SCI population. The optimal training program for changes in lipid lipoprotein profile remains to be determined. However, a minimal aerobic exercise intensity of 70% of heart rate reserve on most days of the week appears to be a good general recommendation for improving lipid lipoprotein profile in persons with SCI.

7.6 Summary

Mounting evidence to suggests that persons with SCI are at an increased risk for CVD. Increasing data indicates that persons with SCI experience an earlier onset and increased prevalence of CVD. Similar to able-bodied individuals, physical inactivity plays a significant role in the risk for CVD in persons with SCI. In fact, the ordinary activities of daily living do not appear to be sufficient to maintain cardiovascular fitness in persons with SCI. Moreover, extremely low levels of physical activity and fitness may lead to a vicious cycle of further decline. Ultimately these changes will have significant implications for the development of CVD (and associated comorbidities) and the ability to live an independent lifestyle. It appears that SCI presents an additional risk for CVD above that observed in able-bodied individuals owing to marked physical deconditioning and injury-related changes in metabolic function (e.g., insulin resistance) (Bravo et al. 2004; Myers et al. 2007).

Physical activity interventions have been shown to be effective at attenuating the progression of CVD and related comorbidities. The forms of exercise interventions are varied, and the experimental data are limited in comparison to other patient populations (i.e., chronic heart failure). However, there is compelling evidence supporting the health benefits of upper extremity aerobic exercise (level 1 and 4) and FES (level 4) training (see Tables 7.13 and 7.14). For instance, there is research indicating that upper extremity exercise at a moderate-to-vigorous intensity, three days/week for at least six weeks, improves cardiovascular fitness and exercise tolerance in persons with SCI. The optimal exercise intervention for improving cardiovascular fitness remains to be determined. There is level 1 evidence (de Groot et al. 2003) that high-intensity (70%–80% HRR) exercise leads to greater improvements in peak power and VO_2peak than low-intensity (50%–60% HRR) exercise. Further investigation is required to determine the relative roles that cardiac and peripheral muscle function play in the improvement of exercise capacity in persons with SCI. There is level 4 (pre-post) evidence that resistance training at a moderate intensity for at least two days/week also appears to be appropriate for the rehabilitation of persons with SCI (Cooney and Walker 1986; Jacobs et al. 2001; Nash et al. 2001; Mahoney et al. 2005).

Table 7.13 Management of the risk for cardiovascular disease in persons with spinal cord injury through aerobic exercise training interventions.

Risk factor		Strength of evidence	Literature support, references
Cardiovascular fitness	• Increased exercise tolerance	Level 1	(Gass et al. 1980; DiCarlo et al. 1983; DiCarlo 1988; Hjeltnes and Wallberg-Henriksson 1998; Jacobs et al. 2002; de Groot et al. 2003; Sutbeyaz et al. 2005)
	• Increased VO_2max	Level 1	(Gass et al. 1980; DiCarlo et al. 1983; Cooney and Walker 1986; DiCarlo 1988; Jacobs et al. 2002; de Groot et al. 2003; El-Sayed et al. 2004; Sutbeyaz et al. 2005)
	• Increased cardiac output	Level 2	(Davis et al. 1987; Davis et al. 1991)
	• Reduced submaximal exercise heart rate	Level 4	(DiCarlo 1988)
	• Increased maximal heart rate	Level 4	(Sutbeyaz et al. 2005)
	• Increased stroke volume	Level 2	(Davis et al. 1987; Davis et al. 1991)
	• Decreased total peripheral resistance	Level 2	(Davis et al. 1987; Davis et al. 1991)
	• Increased power output	Level 1	(Cooney and Walker 1986; DiCarlo 1988; Hjeltnes and Wallberg-Henriksson 1998; Jacobs et al. 2002;

Risk factor		Strength of evidence	Literature support, references
			de Groot et al. 2003; Hicks et al. 2003; Sutbeyaz et al. 2005)
	• Intrinsic cellular adaptations that facilitate oxidative metabolism	Level 4	(Stewart et al. 2004)
Lipid lipoprotein profile	• Increased HDL cholesterol	Level 2	(Hooker and Wells 1989; Nash et al. 2001; El-Sayed and Younesian 2005)
	• Reduced LDL cholesterol	Level 1	(Hooker and Wells 1989; Nash et al. 2001; de Groot et al. 2003; Stewart et al. 2004)
	• Reduced triglycerides	Level 1	(de Groot et al. 2003)
	• Reduced total cholesterol	Level 1	(Hooker and Wells 1989; de Groot et al. 2003; Stewart et al. 2004)
Glucose homeostasis	• Increased insulin sensitivity, decreased insulin resistance, and/or improved glucose tolerance.	Level 1	(de Groot et al. 2003)

Note: HDL = high-density lipoprotein; LDL = low-density lipoprotein.

Table 7.14 Management of the risk for cardiovascular disease in persons with spinal cord injury through functional electrical stimulation training interventions.

Risk factor		Strength of evidence	Literature support, references
Cardiovascular fitness	• Increased exercise tolerance	Level 4	(Pollack et al. 1989; Hooker et al. 1992; Barstow et al. 1996; Mohr et al. 1997; Wheeler et al. 2002; Thijssen et al. 2005)
	• Increased VO_2max	Level 4	(Pollack et al. 1989; Hooker et al. 1992; Barstow et al. 1996; Hjeltnes et al. 1997; Mohr et al. 1997; Wheeler et al. 2002; Thijssen et al. 2005)
	• Increased cardiac output	Level 4	(Hooker et al. 1992)
	• Reduced submaximal exercise heart rate	Level 4	(Faghri et al. 1992)
	• Increased stroke volume	Level 4	(Faghri et al. 1992)
	• Decreased total peripheral/vascular resistance	Level 4	(Faghri et al. 1992)
	• Increased power output	Level 4	(Faghri et al. 1992; Hooker et al. 1992; Thijssen et al. 2005)
	• Intrinsic cellular adaptations that facilitate oxidative metabolism	Level 4	(Andersen et al. 1996; Mohr et al. 1997; Crameri et al. 2002; Crameri et al. 2004)
Lipid lipoprotein profile	• Reduced LDL cholesterol	Level 4	(Solomonow et al. 1997)
	• Reduced total cholesterol	Level 4	(Solomonow et al. 1997)

Risk factor		Strength of evidence	Literature support, references
Glucose homeostasis	• Increased insulin sensitivity, decreased insulin resistance, and/or improved glucose tolerance.	Level 4	(Jeon et al. 2002)

Note: LDL = low-density lipoprotein.

There is growing evidence (predominantly level 4) from several pre-post trials that FES training for a minimum of three days/week for two months can improve oxidative metabolism (Andersen et al. 1996; Mohr et al. 1997; Crameri et al. 2002; Crameri et al. 2004) exercise tolerance (Pollack et al. 1989; Hooker et al. 1992; Barstow et al. 1996; Mohr et al. 1997; Wheeler et al. 2002; Thijssen et al. 2005) and cardiovascular fitness (Pollack et al. 1989; Hooker et al. 1992; Barstow et al. 1996; Hjeltnes et al. 1997; Mohr et al. 1997; Wheeler et al. 2002; Thijssen et al. 2005). There is limited (level 4) evidence (Ditor et al. 2005a; Ditor et al. 2005b) that BWSTT can improve indicators of cardiovascular health in individuals with complete and incomplete SCI.

Preliminary (levels 1 and 4) evidence indicates that aerobic and FES exercise training programs (performed 30 min/day, three days per week for eight weeks or more) are effective in improving glucose homeostasis in persons with SCI (Jeon et al. 2002; de Groot et al. 2003). The magnitude of change in glucose homeostasis appears to be of clinical significance for the prevention and/or treatment of type 2 diabetes in persons with SCI.

There is level 1 evidence from a high-quality RCT (de Groot et al. 2003) and several pre-post studies (Hooker and Wells 1989; Stewart et al. 2004; El-Sayed and Younesian 2005) to suggest that aerobic exercise training programs (performed at a moderate-to-vigorous intensity 20–30 min/day, three days/week for eight weeks) are effective in improving the lipid lipoprotein profiles of persons with SCI. The optimal training program for changes in lipid lipoprotein profile remains to be determined. However, a minimal aerobic exercise intensity of 70% of HRR on most days of the week appears to be a good general recommendation for improving lipid lipoprotein profile. Preliminary level 4 data also indicate that FES training (three hr/week for 14 weeks) may improve lipid lipoprotein profiles in SCI (Solomonow et al. 1997).

As discussed throughout this article, a growing body of evidence supports the existence of an increased risk for CVD and CVD-related mortality in persons with SCI. Marked physical inactivity appears to play a central role in the increased risk for CVD in persons with SCI. Intuitively, exercise training should lead to significant reductions in the risk for CVD and improved overall quality of life in the SCI population. However, the relationship between increasing physical activity and health status of SCI has not been evaluated adequately to date. Based on preliminary evidence (primarily level 4), it would appear that various exercise modalities (including arm ergometry, resistance training, BWSTT, and FES) may attenuate and/or reverse abnormalities in glucose homeostasis, lipid lipoprotein profiles, and cardiovascular fitness. As such, exercise training appears to be an important therapeutic intervention for reducing the risk for CVD and multiple comorbidities (such as type 2 diabetes, hypertension, obesity) in individuals with SCI. Well-designed RCTs are required in the future to establish firmly the primary mechanisms by which exercise interventions elicit these beneficial changes. Similarly, further research is required to evaluate the effects of lesion level and injury severity on exercise prescription, such that exercise programs can be developed that address the varied needs of persons with SCI. Moreover, long-term follow-up investigations are required to determine whether training-induced changes in risk factors for CVD translate directly into a reduced incidence of CVD and premature mortality in persons with SCI.

There is level 4 evidence (Ditor et al. 2005a) that BWSTT improves cardiac autonomic balance in persons with incomplete tetraplegia.

There is level 4 evidence (de Carvalho et al. 2005) that BWSTT can lead to improvements in cardiac autonomic balance in a subset of individuals with motor-complete SCI who respond to ambulation with moderate-to-large increases in heart rate.

Level 4 evidence (Ditor et al. 2005b) indicates that BWSTT can improve arterial compliance in individuals with motor-complete SCI.

There is level 2 evidence (de Carvalho et al. 2006) that neuromuscular electrical stimulation gait training can increase metabolic and cardiorespiratory responses in persons with complete tetraplegia.

There is level 1 evidence (Davis et al. 1987) that moderate intensity aerobic arm training (performed 20–60 min/day, three days/week for at least 6-8 weeks) is effective in improving the aerobic capacity and exercise tolerance of persons with SCI.

There is level 1 evidence (de Groot et al. 2003) that vigorous intensity (70%–80% HRR) exercise leads to greater improvements in aerobic capacity than moderate intensity (50-60% HRR) exercise.

The relative importance of changes in cardiac function and the ability to extract oxygen at the periphery in persons with SCI after aerobic training remains to be determined.

There is level 4 evidence (from pre-post studies that FES training performed for a minimum of three days per week for two months can be effective for improving musculoskeletal fitness, the oxidative potential of muscle, exercise tolerance, and cardiovascular fitness.

There is level 4 evidence that FES training is effective in improving exercise cardiac function in persons with SCI.

There is level 1 (de Groot et al. 2003) and level 4 (Chillibeck et al. 1999; Mohr et al. 2001; Jeon et al. 2002) evidence that both aerobic and FES training (approximately 20–30 min/day, three days/week for eight weeks or more) are effective in improving glucose homeostasis in persons with SCI.

There is level 4 evidence that the changes in glucose homeostasis after aerobic or FES training are clinically significant for the prevention and/or treatment of type 2 diabetes.

There is level 1 evidence (de Groot et al. 2003) to suggest that aerobic exercise training programs (performed at a moderate to vigorous intensity 20-30 min/day, 3 days per week for 8 weeks) are effective in improving the lipid lipoprotein profiles of persons with SCI.

Preliminary evidence (level 4; Solomonow et al. 1997) also indicates that FES training (3 hours/week, for 14 weeks) may improve lipid lipoprotein profiles in SCI.

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