Exercise and Health-Related Risks of Physical Deconditioning After Spinal Cord Injury

Jennifer L. Maher, PhD,¹ David W. McMillan, MS,^{1,2} and Mark S. Nash, PhD, FACSM^{1,3}

¹The Miami Project to Cure Paralysis, University of Miami Miller School of Medicine, Miami, Florida; ²Department of Kinesiology and Sports Sciences, University of Miami, Coral Gables, Florida; ³Departments of Neurological Surgery and Physical Medicine & Rehabilitation, University of Miami Miller School of Medicine, Miami, Florida

A sedentary lifestyle occurring soon after spinal cord injury (SCI) may be in contrast to a preinjury history of active physical engagement and is thereafter associated with profound physical deconditioning sustained throughout the lifespan. This physical deconditioning contributes in varying degrees to lifelong medical complications, including accelerated cardiovascular disease, insulin resistance, osteopenia, and visceral obesity. Unlike persons without disability for whom exercise is readily available and easily accomplished, exercise options for persons with SCI are more limited. Depending on the level of injury, the metabolic responses to acute exercise may also be less robust than those accompanying exercise in persons without disability, the training benefits more difficult to achieve, and the risks of ill-considered exercise both greater and potentially irreversible. For exercise to ultimately promote benefit and not impose additional impairment, an understanding of exercise opportunities and risks if exercise is undertaken by those with SCI is important. The following monograph will thus address common medical challenges experienced by persons with SCI and typical modes and benefits of voluntary exercise conditioning. **Key words:** exercise, fitness, secondary complications, spinal cord injury

Fitness Limitations Occurring After SCI

A sedentary lifestyle either imposed on or adopted by persons with spinal cord injury/disorder (SCI/D) has long ranked them at the lowest end of the human fitness spectrum.¹ In many cases, physical deconditioning after SCI results from muscle paralysis occurring at spinal cord levels that are high enough to make voluntary exercise impossible or unproductive. Additionally, physical, financial, architectural, and transportation barriers may hamper active exercise engagement.² In other instances, persons with SCI simply adopt a sedentary lifestyle or fail to secure the personal assistance and/or equipment needed to assist their training. Notwithstanding a single identified cause for exercise abstention, a 1993 study reported that 1 in 4 healthy, young persons with SCI fails to satisfy a level of fitness needed to perform many essential activities of daily living.³ More recently, it was reported that approximately 50% of patients with SCI report no leisure-time

physical activity and 15% report leisure-time physical activity below the threshold required for meaningful health benefit (<1 hour/week).⁴ This implies that of the estimated 558,000 individuals currently living with SCI in the United States, approximately 279,000 are completely sedentary and another 84,000 participate in leisure-time physical activity inadequate to positively impact health.⁵ Although individuals with sensorimotor sparing of upper limb and trunk functions have far greater capacities for activity and more extensive exercise options,⁶ they are not necessarily more fit than persons with tetraplegia.^{1,7}

A variety of exercise interventions exist that may lead to clinically relevant improvements in health, fitness, and overall function. The focus of this article is on upper extremity, volitional exercise interventions using arm crank ergometry (ACE), wheelchair ergometry (WCE), and circuit resistance training (CRT) as exercise modes to improve cardiovascular and metabolic health, fitness, and function in individuals with SCI/D.

Corresponding author: Jennifer L. Maher, PhD, Department of Neurological Surgery, University of Miami Miller School of Medicine Lois Pope Life Center, 1095 NW 14th Terrace, Miami, FL 33136; phone: 305-243-7122; e-mail: jlmaher@med.miami.edu

---

Top Spinal Cord Inj Rehabil 2017;23(2):175-187
© 2017 Thomas Land Publishers, Inc.
www.thomasland.com

doi: 10.1310/sci2303-175

Secondary Medical/Health Consequences Associated with Physical Deconditioning

Adults with SCI experience an accelerated trajectory of diseases and disorders that resemble those experienced with aging.^{8,9} Characteristic conditions of this accelerated state include atherogenic dyslipidemia and vascular disease,¹⁰⁻¹² arterial circulatory insufficiency,¹³⁻¹⁵ type 2 diabetes and related endocrine disorders,^{16,17} bone and joint diseases,¹⁸ immune dysfunction,¹⁹ and pain of musculoskeletal and neuropathic origins.^{20,21} As physical deconditioning in persons without SCI is widely associated with these conditions,^{22,23} it is reasonable to assume that they are not simply the result of dissociation of the brain from target organs and tissues following trauma and disease of the spinal cord, but might reasonably arise from multiple causes that include physical deconditioning. The following section will examine some of these changes and the putative role played by deconditioning in their evolution.

Body composition

Overweight/obesity is one of the earliest occurring and most common secondary medical complications associated with SCI.²⁴⁻³¹ Increased body fat mass appearing within 2 to 7 months of injury results from decreased daily energy expenditure combined with consumption of nutrients in excess of daily need, including a high percentage of intake from saturated fat.^{32,33} Changes in sublesional body composition typically include atrophy of paralyzed muscles resulting in decreased fat-free mass (FFM)^{34,35} and lipid infiltration of paralyzed limbs.^{36,37} Abdominal obesity is increased in parallel²⁴⁻²⁸ and is attributed to a positive energy balance from an accelerated mitochondrial oxidation of nutrient intake. When occurring together, these modifications in fat metabolism result in an increase in relative adiposity (ie, the percentage of the body as fat),^{34,35,38-40} especially below the level of injury.^{36,37} As a significant mass of this body fat is stored intramuscularly, a body mass index (BMI) of 22 kg/m² has become a suggested criterion for obesity on this population,^{25,41} which by authoritative guidelines represents more than

80% of the SCI population.⁴² This degree of body fat mass is associated with both insulin resistance and elevated levels of atherogenic cytokines,⁴² thus linking obese persons with SCI with 2 major risk determinants of cardiometabolic disease and clinical risks for accelerated pro-atherogenic inflammatory activity.⁴²⁻⁴⁷

Vasomotor control

Cardiovascular regulation can be affected by SCI. Injuries above the cervical enlargement alter sympathetic efferents impeding vasomotor control.⁴⁸⁻⁵⁰ Deconditioning leads to a general decrease in vascular density,⁵¹ which is a predictable response to changes in sublesional composition of the myosin heavy chain phenotype.⁵²⁻⁵⁴ Taken together, this results in an inability to optimally coordinate blood flow at rest and during exercise, which alters the homeostasis of tissue perfusion and control of blood pressure. SCI occurring at the spinal level of T2-T6 can result in complete or subtotal disruption of the sympathetic efferents that innervate the heart,^{50,55,56} resulting in a full or partial knockout of central control of the heart and a neurogenic chronotropic incompetence.⁵⁷ Cardiac structure and function can also be adversely affected in persons with tetraplegia by peripheral unloading of the heart, resulting in reduced cardiac output and end-diastolic functions and subsequent loss of left ventricular mass.^{58,59} The lowered cardiac output is also apparent in persons of all lesion levels from loss of lower extremity muscle pumping and a declining venous return,^{60,61} as well as lower blood volume^{60,62} and increased vascular resistance to blood flow.⁶²

Dysglycemia

Disorders of fasting carbohydrate metabolism occurring as insulin resistance and clinical type 2 diabetes were first documented in persons with SCI by Duckworth and colleagues⁶³ and later confirmed by other investigators.⁶⁴⁻⁶⁸ Others have observed dysglycemia in times of energy flux. Libin and colleagues²⁹ and others^{69,70} have reported that fasting plasma glucose and glycated hemoglobin A1c are relatively less impaired than

other metabolic risk factors, and they observed that unstimulated postabsorptive glucose uptake is not substantially impaired after SCI. In parallel, microdialysis studies have shown that resting uptake of free fatty acids (FFA) and glucose within flaccid muscles does not differ from that of muscles that are neurologically intact,⁷¹ whereas spastic paralysis can increase resting glucose uptake of skeletal muscle above non-injured controls.⁷² However, resting measures are not a holistic proxy for disorders of carbohydrate metabolism⁷³⁻⁷⁵; when an oral glucose challenge is performed, it is observed that persons with SCI having typical plasma glucose very often have impaired glucose tolerance.^{37,76-81} This phenomenon was observed in a study by Segal and colleagues⁸² who found that 94% of a sample of 31 persons with SCI had clinically impaired glucose tolerance despite all individuals having clinically “normal” fasting plasma glucose. As persons with SCI often require substantially increased insulin levels to achieve similar plasma glucose at rest^{83,84} or during glucose ingestion,⁸⁵⁻⁸⁷ these findings can be explained by changes in peripheral insulin signaling,^{76,88} blunted insulin delivery,⁸⁴ and/or impaired insulin catabolism.⁷⁹ These findings are not surprising given that skeletal muscle is the primary site of insulin-mediated glucose uptake⁸⁹⁻⁹¹; but as the majority of whole body glucose uptake is non-insulin dependent,^{91,92} other mechanisms that contribute to fasting and challenge dysglycemia must be considered. Mechanisms specific to SCI are likely involved to some degree, as the difference in oral glucose tolerance between persons with and without SCI is not entirely accounted for by differences in body composition.⁹³

Dyslipidemia

Extensive evidence documents an accelerated course for all-cause cardiovascular disease in the SCI population.^{44,94-98} Recent retrospective and meta-analytic studies examining the fasted serum lipid panel in persons with SCI have reported lipid disorders in this population, with persons with tetraplegia tending to have depressed high-density lipoprotein cholesterol (HDL-C) concentration⁹⁹ and those with paraplegia having elevated concentrations of total cholesterol (TC)

and non-HDL-C.¹⁰⁰ The combination of low HDL-C and either normal or elevated TC explains a high-risk cardiovascular disease projection, as the ratio of TC to HDL-C above a cut score of 4.5 typically predicts this risk.^{10,44,101} Several mechanisms have been suggested for the unique and reproducible low HDL-C concentration. Endothelial lipase (EL) catabolizes HDL-C¹⁰² and thus may become overactive after SCI. Another explanation is that decreased blood flow to target tissues could decrease delivery of chylomicrons and very low-density lipoproteins (VLDL) to lipases resulting in decreased HDL-like chylomicron components (which are a byproduct of chylomicron and VLDL catabolism) required for HDL-C synthesis.¹⁰³ Finally, elevated inflammatory stress such as accompanying SCI^{42,47,104,105} has been shown to upregulate EL¹⁰⁶ and downregulate other lipoprotein¹⁰⁷ and hepatic¹⁰⁸ lipases, as illustrated by the acute and transient plummet in HDL levels during inflammatory shock accompanying sepsis.^{109,110}

Beyond fasting dyslipidemia, evidence from several studies has shown an exaggerated postprandial lipemia in which delayed disposal of ingested triglycerides leads to the formation of triglyceride (TG)-rich lipoproteins and an elevated cardiovascular disease (CVD) risk.^{111,112} Uptake of TG-rich lipoproteins then stimulates pathogenic VLDL assembly and secretion as the liver attempts to maintain homeostasis of its fatty acid and TG levels. Delivery of excess remnant TG from delayed disposal leads to increased VLDL secretion, a cycle that has been demonstrated in insulin-resistant individuals.¹¹³ The risk posed by delayed metabolism of ingested triglycerides is recognized to be greater than fasting triglyceridemia^{114,115} and is associated with abdominal obesity in persons both with SCI¹¹² and without.¹¹⁶

Exercise as an Evidence-Based Countermeasure to Secondary Complications

Exercise is a fundamental element in maintaining physical capacity and cardiovascular and metabolic health for persons of all ages and health states. The American College of Sports Medicine (ACSM) defines exercise as “a type of physical activity consisting of planned, structured,

and repetitive bodily movements to improve and/or maintain one or more components of physical fitness.”^{117(p2)} The unified ACSM and the World Health Organization (WHO) guidelines¹¹⁸ prescribe exercise and provide physical activity guidelines for supporting health and wellness in the general population (**Table 1**), which are also recommended for individuals with SCI.¹¹⁷ These guidelines are in substantial agreement with both the ACSM Guidelines for Exercise Testing and Prescription (9th ed.)¹¹⁸ and the Physical Activity Guidelines for Adults with SCI that were established for SCI Action Canada.¹¹⁹ They are also similar to the Physical Fitness for Special Populations (PFSP) “Physical Fitness for Individuals with Spinal Cord Injury” recommendations of the American Physical Therapy Association.¹²⁰

Volitional exercise using arm-crank ergometry, reciprocating ergometry (**Figure 1**), wheelchair propulsion, hand cycling, and circuit resistance training has been widely recommended to improve cardiovascular fitness, metabolic health, and physical capacity in individuals with SCI/D.¹²¹⁻¹²⁴ A growing body of evidence specifically supports the beneficial effect of such exercise on risks of dyslipidemia, glycemia, and visceral adiposity as well as on physical capacity measures in individuals with SCI/D. This evidence has been comprehensively reviewed in a number of scholarly monographs.^{45,121,122,125-130}

Figure 1. Reciprocating ergometer.

Levels of Physical Capacity After SCI/D

Physical capacity is the ability of the cardiovascular system, muscle groups, and the respiratory system to support the desired level of physical activity.¹³¹ Physical capacity is reduced in SCI/D (**Table 2**), with a greater reduction seen in those with tetraplegia. Its evaluation can give an indication of potential levels of participation in physical activity

Table 1. Exercise guidelines to improve health and wellness in individuals with SCI/D

Aerobic exercise		
Intensity	Moderate	Vigorous
Weekly total ^a	≥ 150 min	≥ 75
Lay intensity guide	“Somewhat hard.” “You can talk but not sing.” 5 or 6 on a 0-10 scale	“Really hard.” “You can’t say more than a few words without pausing for breath.” 7 or 8 on a 0-10 scale
Resistance training		
Frequency	2-3 days per week	
Number of exercises	All major muscle groups (~ 4-5 upper body exercises)	
Sets and repetitions	Three sets of 8-12 reps each exercise	
Weight	Enough to create a feeling of “quite challenged” at the end of each set	

Note: SCI/D = spinal cord injury/disorder.

^aCan be accrued in ≥ 10 min bouts.

Table 2. Average $\text{VO}_{2\text{peak}}$ and PO_{peak} in individuals with paraplegia, tetraplegia, and age-matched nondisabled individuals^{115,150}

	PP		TP		ND	
	M	F	M	F	M	F
Test modality	Arm ergometry		Arm ergometry		Treadmill	
Age, years	36.0 ± 9.0	33.6 ± 10.2	35.0 ± 10.3	40.0 ± 7.0	30-39	30-49
$\text{VO}_{2\text{peak}}$, mL/kg/min	16.5	13.21	8.71	9.37	42.4	34.3
PO_{peak} , W/kg	0.92	0.71	0.20	0.19	NA	NA

Note: Distribution of participants was PP, $n = 109$; TP, $n = 68$; American Spinal Injury Association Impairment Scale A, $n = 42$; AIS B, $n = 17$; AIS C, $n = 3$; AIS D, $n = 1$. PP and TP age values are given as mean ± SD; ND age values are given as range. F = female; M = male; ND = nondisabled; PO_{peak} = relative peak power output; PP = paraplegia; TP = tetraplegia; $\text{VO}_{2\text{peak}}$ = relative peak oxygen consumption.

and exercise, community participation, and quality of life.¹²⁸ Peak oxygen consumption, or aerobic capacity ($\text{VO}_{2\text{peak}}$), and peak power output (PO_{peak}) have proven to be valid and sensitive outcome measures for the assessment of physical capacity in individuals with SCI/D.¹³¹ Aerobic capacity is pertinent for cardiovascular health and fatigue resistance,¹²⁹ whereas power output has the greatest impact on the ability to perform functional wheelchair maneuvers¹³² and transfers, all of which are critical for independence and a higher functional status.¹³³ Exercise seems to be effective in improving these outcomes in individuals with SCI, however, supporting evidence is somewhat limited in contrast to the general population and even other clinical disorders.

Effects of Exercise on Physical Capacity

Intervention protocols vary greatly among studies that have examined upper body exercise in SCI/D. ACE and WCE are the most frequently cited training modes, while circuit resistance training, often combined with ACE, and strength training are used as well. Training intensities also differ, employing a range of indices for workload varying between 40% and 90% of heart rate reserve (HRR), peak heart rate (HR_{peak}), $\text{VO}_{2\text{peak}}$, or PO_{peak} . The frequency of training and duration of sessions and training period are also variable, ranging from 1 to 3 days per week, 20 to 120 minutes and 4 to 32 weeks, respectively.¹³⁰

Volitional exercise to improve aerobic capacity and power output

Extensive evidence documents the effectiveness of all training modes to improve cardiopulmonary conditioning. Early research cited 99% and 24% improvements in $\text{VO}_{2\text{peak}}$ and PO_{peak} ,¹³⁴ respectively, in individuals with tetraplegia following 8 weeks of ACE or WCE training. However, most studies report average posttraining improvements of approximately 10% to 30%^{130,135} for these outcome measures. A study evaluating the effects of both low-intensity (50%-60% of maximum HRR) and moderate-intensity (70%-80% of maximum HRR) 8-week WCE training programs performed 3 times per week for 20 minutes daily reported mean percentage increases in $\text{VO}_{2\text{peak}}$ and PO_{peak} of 10% and 24% and 12% and 13%, respectively. While fitness was improved in both low- and moderate-intensity groups, improvements in submaximal exercise observed that only moderate-intensity WCE promoted a significant training effect.¹³⁶ After completion of a 16-week primary rehabilitation program involving 30-minute ACE sessions performed 3 times per week, Hjeltne and Wallberg-Henriksson¹³⁷ reported significant improvements in PO_{peak} in individuals with paraplegia and tetraplegia. However, improvements in $\text{VO}_{2\text{peak}}$ were only seen in individuals with paraplegia. A recent study examined the relationship between physical activity and wheelchair-specific fitness, reporting

a significant positive association between physical activity and PO_{peak} for individuals with tetraplegia.¹³⁸

Less research exists on the effects of resistance training on cardiopulmonary fitness. A twice weekly, 12- to 16-week CRT program for persons with SCI/D improved VO_{2peak} by nearly 30%, providing convincing evidence for the employment of a moderate-intensity effort exercise to improve aerobic capacity. CRT may satisfy authoritative guidelines for incorporation of resistance training into the overall exercise conditioning plan better than ACE and WCE, while improving upper extremity strength and anaerobic power needed to support essential activities of daily living.^{139,140}

Exercise Training on Secondary Complications

Upper body volitional exercise and dyslipidemia after SCI/D

As noted, dyslipidemia is a widely reported health risk after SCI/D.^{10,16,46} Lowered HDL-C is normally associated with and is likely a direct result of a sedentary lifestyle,¹³⁹ as cross-sectional studies in individuals with SCI/D observe an association between low peak aerobic capacities and low HDL-C¹⁰⁴ and also consistently find less atherogenic lipid profiles in those who are habitually highly active or physically fit.¹⁴¹

In subjects with SCI/D, a prospective interventional study investigating effects of a moderate-intensity (70%-80% of maximum HRR) 8-week WCE training program performed 20 minutes daily and 3 times weekly reported increased HDL-C and decreases in TG, LDL-C,

and TC:HDL-C ratio,¹³⁶ the latter a proxy for global CVD risk. Noteworthy was the finding that the observed benefit was limited to those participants undergoing moderate-intensity training and not low-intensity conditioning. A more recent study examining moderate-intensity ACE demonstrated similar intensity-dependent beneficial effects on the lipid profile of individuals with SCI/D.¹⁴² An intensity-dependent benefit of exercise was further shown in a 2003 study by de Groot et al¹⁴³ when comparing high- and low-intensity interval training programs, in which participants with SCI/D undergoing higher intensity work demonstrated more pronounced lowering of both fasting TG and the TC:HDL ratio.

As adoption of WCE and ACE as exercise conditioning modes may not be best suited for long-term use by persons with SCI/D and may also not engender essential long-term compliance, the need for higher work intensities to achieve improved lipid profiles can be readily satisfied by use of interval training. CRT using a series of alternating resistance exercises and low-resistance arm ergometry has been described for persons with both paraplegia and tetraplegia (**Table 3**).¹⁴⁴ A 12-week CRT program for persons with SCI/D lowered LDL-C, increased HDL-C, and reduced both LDL:HDL and TC:HDL ratios in men.¹⁰¹ These improvements reflected a CV risk reduction by almost 25%,¹⁰¹ a benefit also reported in a cohort of middle-aged men with paraplegia who underwent an identical CRT program for 16 weeks.¹⁴⁰ Other studies of twice-weekly CRT report similar benefits of circuit training on dyslipidemia.¹⁴⁵

Table 3. Circuit resistance training (CRT) program

Exercises	Instructions
Arm ergometer	- Resistance exercises will be performed in pairs, each incorporating 10 repetitions of each maneuver (6 second movement; 3 seconds concentric [lifting] and 3 seconds eccentric [lowering]). Resistive loads for training will be 50% of the individual's 1-repetition maximal (1-RM) values. - Two minutes of endurance exercise is then interposed on an arm ergometer at a cadence of 50 rpm without applied resistance. - Then, 2 more resistance maneuvers are performed. These activities are alternated until subjects have rotated through each resistance station 3 times for a total of 3 sets of 10 repetitions for 6 upper body lifts and 20 minutes of arm ergometry.
Military press	
Horizontal rows	
Chest fly	
Preacher curls	
Latissimus pull-down	
Seated dips	
Perform CRT 3 times weekly on nonconsecutive days. Each session lasts approximately 40 to 45 minutes.	

Upper body volitional exercise to improve insulin sensitivity/glycemic response

Early studies in SCI/D report subjects with diabetes having significantly higher average glucose-stimulated plasma insulin levels than those individuals with normal glucose tolerance, suggesting a common state of insulin resistance.^{63,64} This risk has been attributed to postinjury changes in body composition as well as reduced levels of exercise and non-exercise physical activity. A cross-sectional study of persons with SCI/D reported an association between low activity levels and higher fasting glucose,¹⁰⁴ while a similar study found that 23% more physically inactive individuals than active people with SCI/D were classified as insulin resistant.¹⁴⁶

It is well documented that exercise can reduce insulin resistance and improve insulin sensitivity.^{147,148} A recent cross-sectional study examining glucose homeostasis in physically active and non-active individuals with chronic SCI/D reported significantly lower fasting plasma insulin and homeostasis model assessment of insulin resistance (HOMA-IR) values in persons undertaking regular physical activity.¹⁴⁹ Upper extremity interval training programs also appear to be an effective method for improving insulin sensitivity,^{143,150} with a recent study¹⁵¹ reporting 37% and 40% reductions in fasting insulin and HOMA-IR levels, respectively, after a 6-week indoor hand-cycle exercise program.

Upper body volitional exercise to attenuate central obesity

While beneficial effects of exercise on dyslipidemia and dysglycemia are well supported after SCI/D, less persuasive evidence documents the impact of exercise monotherapy on overall body composition,^{152,153} especially the clinically significant loss of body fat mass (FM). The gain in FM after SCI/D is clearly associated with physical immobilization, but it is also attributable to alterations in sympathoadrenal medullary function accompanying SCI/D and to a great extent to food intake that is hypercaloric for daily needs.^{32,33,154} Higher abdominal sagittal diameters

have been associated with low activity levels in SCI/D,¹⁰⁴ while individuals who engage in regular exercise had 39% lower total FM, up to 48% lower FM in the trunk,^{69,149} and greater percent FFM¹⁴⁶ than those who did not regularly engage in exercise.

Notwithstanding these risks, evidence suggests a beneficial effect of exercise monotherapy on body metabolism and composition.¹⁵⁵ For example, a 16-week interval hand-cycling program performed by people with chronic SCI resulted in a significant reduction of waist circumference (3.1 cm; 3.5%) and trunk (3.6%) and android (4.7%) fat percentage.¹⁵⁰ A recent study yielding promising results compared persons who achieved the 150 minutes of moderate-intensity exercise per week recommended by the ACSM and WHO for sedentary individuals. Subjects who reached the target exercise recommendations had approximately 12% greater FFM and approximately 10% lower FM than those who did not, further confirming that the ACSM and WHO guidelines for healthy adults are useful as a guide for individuals with SCI/D.¹⁵²

Physical Capacity and Measures of Function and Independence After SCI/D

Decreased physical capacity is associated with an increase in secondary health complications, as well as a decrease in function and ability to perform activities of daily living (ADLs) such as self-care activities, work activities, and household chores. A growing body of literature points to physical capacity as a key factor in determining independence in individuals with SCI/D.^{3,132,133,156} Early cross-sectional research identified a significant correlation between $\text{VO}_{2\text{peak}}$ and functional ability, especially in individuals with high-level spinal cord lesions.³ Highly fit individuals with high-level lesions were shown to have levels of functional independence that are similar to those of individuals with paraplegia.³ More recently, Dallmeijer et al reported that after correction for lesion level in chronic SCI, fitness explained 22% of the variance in functional status (SIP68).¹³³ A longitudinal study reported that the fitness level at discharge from rehabilitation

was a more impactful predictor than lesion level of functional status (FIM motor scores) 1 year later.¹⁵⁶

Although cross-sectional studies appear to support the relationship between fitness and function, interventional research testing these relationships is more limited. A study of 13 individuals with chronic thoracic SCI identified improvement in FIM scores after a 16-week exercise program consisting of mobility, strength coordination, aerobic, resistance, and relaxation activities.¹⁵⁷ Conversely, it has been reported in acute patients with tetraplegia that improvements in ADLs, as assessed by the Sunnaas Hospital Activities of Daily Life Index, are not necessarily followed or preceded by improvements in fitness. Individuals were assessed during an inpatient primary rehabilitation period that included 30-minute sessions of ACE 3 times per week for approximately 16 weeks. Muscle strength, exercise capacity and tolerance, and ADL performance were significantly improved following the exercise intervention. However, no improvements in VO_{2peak} were observed.¹³⁷

In most instances evidence appears to support a relationship between physical capacity and independence, but the nature of this association remains unclear. Face validity would suggest that individuals with higher physical capacity would benefit by having more advanced functional abilities. However, it is also conceivable that those individuals with better functional abilities may be more capable of maintaining appropriate fitness levels.¹³³ Many factors likely affect this relationship, such as neurological impairment, age, injury duration, and general fitness level. It

is important to note that an individual who is unskilled in the performance of daily activities might not necessarily improve their function simply by enhancing fitness. Thus, the role of these relationships must be more extensively understood so that exercise interventions can better target and enhance the important attributes of function and independence.

Conclusions

Habitual exercise is an effective countermeasure for addressing physical deconditioning after SCI. Evidence supports a role for chronic exercise in prevention and treatment of secondary complications associated with dyslipidemia and insulin resistance. It is likely that exercise assists in maintaining a stable body weight or promoting a reduction in body mass, although less experimental evidence supports the use of exercise as a monotherapy for weight loss after SCI. Loss of body mass may be more effectively achieved by combining exercise with caloric restriction and dietary intake with reduced intake of saturated fats. Additional research suggests that function and independence may be improved by increasing physical capacity. However, the extent to which physical capacity must be increased in order to elicit gains in function remains unknown. Further, benefits may depend on levels of skill in performing daily activities. An upper body exercise program should be the cornerstone of a comprehensive lifestyle treatment plan for persons with SCI, especially if optimal health and function are to be maintained throughout the lifespan.

REFERENCES

1. Dearwater SR, LaPorte RE, Robertson RJ, Brenes G, Adams LL, Becker D. Activity in the spinal cord-injured patient: An epidemiologic analysis of metabolic parameters. *Med Sci Sports Exerc.* 1986;18(5):541-544.
2. Cowan RE, Nash MS, Anderson KD. Exercise participation barrier prevalence and association with exercise participation status in individuals with spinal cord injury. *Spinal Cord.* 2013;51(1):27-32.
3. Noreau L, Shephard RJ, Simard C, Pare G, Pomerleau P. Relationship of impairment and functional ability to habitual activity and fitness following spinal cord injury. *Int J Rehabil Res.* 1993;16(4):265-275.
4. Ginis KA, Latimer AE, Arbour-Nicitopoulos KP, et al. Leisure time physical activity in a population-based sample of people with spinal cord injury part I: Demographic and injury-related correlates. *Arch Phys Med Rehabil.* 2010;91(5):722-728.
5. Miller LE, Herbert WG. Health and economic benefits of physical activity for patients with spinal cord injury. *Clinicoecon Outcomes Res.* 2016;8:551-558.
6. Simmons OL, Kressler J, Nash MS. Reference fitness values in the untrained spinal cord injury population. *Arch Phys Med Rehabil.* 2014;95(12):2272-2278.

7. Bostom AG, Toner MM, McArdle WD, Montelione T, Brown CD, Stein RA. Lipid and lipoprotein profiles relate to peak aerobic power in spinal cord injured men. *Med Sci Sports Exerc.* 1991;23(4):409-414.
8. Gerhart KA, Bergstrom E, Charlifue SW, Menter RR, Whiteneck GG. Long-term spinal-cord injury – functional changes over time. *Arch Phys Med Rehabil.* 1993;74(10):1030-1034.
9. Ohry A, Shemesh Y, Rozin R. Are chronic spinal cord injured patients (SCIP) prone to premature aging? *Med Hypotheses.* 1983;11(4):467-469.
10. Nash MS, Mendez AJ. A guideline-driven assessment of need for cardiovascular disease risk intervention in persons with chronic paraplegia. *Arch Phys Med Rehabil.* 2007;88(6):751-757.
11. Bauman W, Spungen A. Coronary heart disease in individuals with spinal cord injury: Assessment of risk factors. *Spinal Cord.* 2008;46(7):466-476.
12. Phillips WT, Kiratli BJ, Sarkarati M, et al. Effect of spinal cord injury on the heart and cardiovascular fitness. *Curr Probl Cardiol.* 1998;23(11):641-716.
13. Hopman MT, Monroe M, Dueck C, Phillips WT, Skinner JS. Blood redistribution and circulatory responses to submaximal arm exercise in persons with spinal cord injury. *Scand J Rehabil Med.* 1998;30(3):167-174.
14. Jacobs PL, Mahoney ET, Robbins A, Nash M. Hypokinetic circulation in persons with paraplegia. *Med Sci Sports Exerc.* 2002;34(9):1401-1407.
15. Hjeltnes N. Oxygen uptake and cardiac output in graded arm exercise in paraplegics with low level spinal lesions. *Scand J Rehabil Med.* 1977;9(3):107-113.
16. Bauman WA, Spungen AM. Metabolic changes in persons after spinal cord injury. *Phys Med Rehabil Clin N Am.* 2000;11(1):109-140.
17. Nash MS, Tractenberg RE, Mendez AJ, et al. Cardiometabolic syndrome in people with spinal cord injury/disease: Guideline-derived and nonguideline risk components in a pooled sample. *Arch Phys Med Rehabil.* 2016;97(10):1696-1705.
18. Bauman WA. Risk factors for osteoporosis in persons with spinal cord injury: What we should know and what we should be doing. *J Spinal Cord Med.* 2004;27(3):212-213.
19. Nash MS. Known and plausible modulators of depressed immune functions following spinal cord injuries. *J Spinal Cord Med.* 2000;23(2):111-120.
20. Widerstrom-Noga EG, Felipe-Cuervo E, Yezierski RP. Relationships among clinical characteristics of chronic pain after spinal cord injury. *Arch Phys Med Rehabil.* 2001;82(9):1191-1197.
21. Bryce TN, Biering-Sorensen F, Finnerup NB, et al. International Spinal Cord Injury Pain Classification: part I. Background and description. *Spinal Cord.* 2012;50(6):413-417.
22. Chodzko-Zajko W, Schwingel A, Park CH. Successful aging: The role of physical activity. *Am J Lifestyle Med.* 2009;3(1):20-28.
23. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sport Exerc.* 2009;41(7):1510-1530.
24. Gorgey AS, Gater DR. Prevalence of obesity after spinal cord injury. *Top Spinal Cord Inj Rehabil.* 2007;12(Spring):1-7.
25. Buchholz AC, Bugaresti JM. A review of body mass index and waist circumference as markers of obesity and coronary heart disease risk in persons with chronic spinal cord injury. *Spinal Cord.* 2005;43(9):513-518.
26. Gater DR, Jr. Obesity after spinal cord injury. *Phys Med Rehabil Clin N Am.* 2007;18(2):333-351, vii.
27. Nash MS, Gater DR. Exercise to reduce obesity in SCI. *Top Spinal Cord Inj Rehabil.* 2007;12(4):76-93.
28. Kressler J, Cowan RE, Bigford GE, Nash MS. Reducing cardiometabolic disease in spinal cord injury. *Phys Med Rehabil Clin N Am.* 2014;25(3):573-604, viii.
29. Libin A, Tinsley EA, Nash MS, et al. Cardiometabolic risk clustering in spinal cord injury: results of exploratory factor analysis. *Top Spinal Cord Inj Rehabil.* 2013;19(3):183-194.
30. Groah SL, Nash MS, Ward EA, et al. Cardiometabolic risk in community-dwelling persons with chronic spinal cord injury. *J Cardiopulm Rehabil Prevent.* 2011;31(2):73-80.
31. Gorgey AS, Gater DR. Prevalence of obesity after spinal cord injury. *Top Spinal Cord Inj Rehabil.* 2007;12(4):1-7.
32. Groah SL, Nash MS, Ljungberg IH, et al. Nutrient intake and body habitus after spinal cord injury: An analysis by sex and level of injury. *J Spinal Cord Med.* 2009;32(1):25-33.
33. Levine AM, Nash MS, Green BA, Shea JD, Aronica MJ. An examination of dietary intakes and nutritional status of chronic healthy spinal cord injured individuals. *Paraplegia.* 1992;30(12):880-889.
34. Nuhlicek DN, Spurr GB, Barboriak JJ, Rooney CB, el Ghatit AZ, Bongard RD. Body composition of patients with spinal cord injury. *Eur J Clin Nutr.* 1988;42(9):765-773.
35. Modlesky CM, Bickel CS, Slade JM, Meyer RA, Cureton KJ, Dudley GA. Assessment of skeletal muscle mass in men with spinal cord injury using dual-energy X-ray absorptiometry and magnetic resonance imaging. *J Appl Physiol.* 2004;96(2):561-565.
36. Gorgey AS, Dudley GA. Skeletal muscle atrophy and increased intramuscular fat after incomplete spinal cord injury. *Spinal Cord.* 2007;45(4):304-309.
37. Elder CP, Apple DF, Bickel CS, Meyer RA, Dudley GA. Intramuscular fat and glucose tolerance after spinal cord injury--a cross-sectional study. *Spinal Cord.* 2004;42(12):711-716.
38. Gorgey AS, Gater DR. Prevalence of obesity after spinal cord injury. *Top Spinal Cord Inj Rehabil.* 2007;12(4):1-7.
39. Gater DR, Jr. Obesity after spinal cord injury. *Phys Med Rehabil Clin N Am.* 2007;18(2):333-351, vii.
40. Wong S, Derry F, Jamous A, Hirani SP, Grimble G, Forbes A. The prevalence of malnutrition in spinal cord injuries patients: A UK multicentre study. *Brit J Nutr.* 2012;108(5):918-923.
41. Loughton GE, Buchholz AC, Martin Ginis KA, Goy RE. Lowering body mass index cutoffs better identifies obese persons with spinal cord injury. *Spinal Cord.* 2009;47(10):757-762.

42. Nash MS, Tractenberg RE, Mendez AJ, et al. Cardiometabolic syndrome in people with spinal cord injury/disease: Guideline-derived and non-guideline risk components in a pooled sample. *Arch Phys Med Rehabil*. 2016;97(10):1696-1705.
43. Groah SL, Hosier H, Ward EA, Nash M, Libin A, Taylor AJ. Cardiometabolic risk clustering and atherosclerosis: Is there a link in spinal cord injury? *Top Spinal Cord Inj Rehabil*. 2011;16(3):1-13.
44. Groah SL, Nash MS, Ward EA, et al. Cardiometabolic risk in community-dwelling persons with chronic spinal cord injury. *J Cardiopulm Rehabil Prevent*. 2011;31(2):73-80.
45. Kressler J, Cowan RE, Bigford GE, Nash MS. Reducing cardiometabolic disease in spinal cord injury. *Phys Med Rehabil Clin N Am*. 2014;25(3):573-604, viii.
46. Libin A, Tinsley E, Nash M, et al. Cardiometabolic risk clustering in spinal cord injury: Results of exploratory factor analysis. *Top Spinal Cord Inj Rehabil*. 2013;19(3):183-194.
47. Nash MS, Dalal KL, Martinez-Barrizonte J, Cardenas DD. Suppression of proatherogenic inflammatory cytokines as a therapeutic countermeasure to CVD risks accompanying SCI. *Top Spinal Cord Inj Rehabil*. 2011;16(3):14-32.
48. da Silva AA, do Carmo JM, Wang Z, Hall JE. The brain melanocortin system, sympathetic control, and obesity hypertension. *Physiology*. 2014;29(3):196-202.
49. Guyenet PG. The sympathetic control of blood pressure. *Nat Rev Neurosci*. 2006;7(5):335-346.
50. Dela F, Mohr T, Jensen CMR, et al. Cardiovascular control during exercise - Insights from spinal cord-injured humans. *Circulation*. 2003;107(16):2127-2133.
51. Phillips AA, Cote AT, Warburton DER. A systematic review of exercise as a therapeutic intervention to improve arterial function in persons living with spinal cord injury. *Spinal Cord*. 2011;49(6):702-714.
52. Castro MJ, Apple DF, Hillegass EA, Dudley GA. Influence of complete spinal cord injury on skeletal muscle cross-sectional area within the first 6 months of injury. *Eur J Appl Physiol Occup Physiol*. 1999;80(4):373-378.
53. Castro MJ, Apple DF, Melton-Rogers S, Dudley GA. Muscle fiber type-specific myofibrillar Ca(2+) ATPase activity after spinal cord injury. *Muscle Nerve*. 2000;23(1):119-121.
54. Castro MJ, Apple DF, Rogers S, Dudley GA. Influence of complete spinal cord injury on skeletal muscle mechanics within the first 6 months of injury. *Eur J Appl Physiol*. 2000;81(1-2):128-131.
55. McDougall SJ, Widdop RE, Lawrence AJ. Central autonomic integration of psychological stressors: Focus on cardiovascular modulation. *Autonom Neurosci Basic Clin*. 2005;123(1-2):1-11.
56. Coote JH. A role for the paraventricular nucleus of the hypothalamus in the autonomic control of heart and kidney. *Exp Physiol*. 2005;90(2):169-173.
57. Bravo G, Guizar-Sahagun G, Ibarra A, Centurion D, Villalon CM. Cardiovascular alterations after spinal cord injury: An overview. *Curr Med Chem Cardiovasc Hematol Agents*. 2004;2(2):133-148.
58. Kessler KM, Pina I, Green B, et al. Cardiovascular findings in quadriplegic and paraplegic patients and in normal subjects. *Am J Cardiol*. 1986;58(6):525-530.
59. Nash MS, Bilsker S, Marcillo AE, et al. Reversal of adaptive left ventricular atrophy following electrically-stimulated exercise training in human tetraplegics. *Paraplegia*. 1991;29(9):590-599.
60. Nash MS, Mintz CD, Montalvo BM, Jacobs PL. A randomized blinded comparison of two methods used for venous antistasis in tetraplegia. *J Spinal Cord Med*. 2000;23(4):221-227.
61. de Groot PC, Bleeker MW, van Kuppevelt DH, van der Woude LH, Hopman MT. Rapid and extensive arterial adaptations after spinal cord injury. *Arch Phys Med Rehabil*. 2006;87(5):688-696.
62. Hopman MT, Groothuis JT, Flendrie M, Gerrits KH, Houtman S. Increased vascular resistance in paralyzed legs after spinal cord injury is reversible by training. *J Appl Physiol*. 2002;93(6):1966-1972.
63. Duckworth WC, Solomon SS, Jallepalli P, Heckemeyer C, Finnern J, Powers A. Glucose intolerance due to insulin resistance in patients with spinal cord injuries. *Diabetes*. 1980;29(11):906-910.
64. Bauman WA, Spungen AM. Disorders of carbohydrate and lipid metabolism in veterans with paraplegia or quadriplegia: A model of premature aging. *Metabolism*. 1994;43(6):749-756.
65. Bauman WA, Spungen AM. Carbohydrate and lipid metabolism in chronic spinal cord injury. *J Spinal Cord Med*. 2001;24(4):266-277.
66. Kressler J, Cowan RE, Bigford GE, Nash MS. Reducing cardiometabolic disease in spinal cord injury. *Phys Med Rehabil Clin N*. 2014;25(3):573-604, viii.
67. Bigford GE, Bethea JR, Nash MS. Pro-inflammatory signaling in peripheral tissue related to cardiometabolic dysfunction and diabetes in chronic spinal cord injury. *Top Spinal Cord Inj Rehabil*. 2013;19(S1):18.
68. Cragg JJ, Noonan VK, Dvorak M, Krassioukov A, Mancini GB, Borisoff JF. Spinal cord injury and type 2 diabetes: Results from a population health survey. *Neurology*. 2013;81(21):1864-1868.
69. Jones LM, Legge M, Goulding A. Factor analysis of the metabolic syndrome in spinal cord-injured men. *Metabolism*. 2004;53(10):1372-1377.
70. Liang H, Chen D, Wang Y, Rimmer JH, Braunschweig CL. Different risk factor patterns for metabolic syndrome in men with spinal cord injury compared with able-bodied men despite similar prevalence rates. *Arch Phys Med Rehabil*. 2007;88(9):1198-1204.
71. Kjaer M, Dela F, Sorensen FB, et al. Fatty acid kinetics and carbohydrate metabolism during electrical exercise in spinal cord-injured humans. *Am J Physiol Regul Integr Comp Physiol*. 2001;281(5):R1492-1498.
72. Bennegard GM, Karlsson AK. Higher glucose uptake in paralysed spastic leg. *Spinal Cord*. 2008;46(2):103-106.
73. Ceriello A. Point: postprandial glucose levels are a clinically important treatment target. *Diabetes Care*. 2010;33(8):1905-1907.

74. Nathan DM, Davidson MB, DeFronzo RA, et al. Impaired fasting glucose and impaired glucose tolerance: Implications for care. *Diabetes Care*. 2007;30(3):753-759.
75. Aronoff SL, Berkowitz K, Shreiner B, Want L. Glucose metabolism and regulation: Beyond insulin and glucagon. *Diabetes Spectrum*. 2004;17(3):183-190.
76. Yazar-Fisher C, Bickel CS, Windham ST, McLain AB, Bamman MM. Skeletal muscle signaling associated with impaired glucose tolerance in spinal cord-injured men and the effects of contractile activity. *J Appl Physiol*. 2013;115(5):756-764.
77. Myllynen P, Koivisto VA, Nikkila EA. Glucose intolerance and insulin resistance accompany immobilization. *Acta Medica Scand*. 1987;222(1):75-81.
78. Lewis JG, Jones LM, Legge M, Elder PA. Corticosteroid-binding globulin, cortisol, free cortisol, and sex hormone-binding globulin responses following oral glucose challenge in spinal cord-injured and able-bodied men. *Horm Metab Res*. 2010;42(12):882-886.
79. Aksnes AK, Brundin T, Hjeltne N, Wahren J. Glucose-induced thermogenesis in tetraplegic patients with low sympathoadrenal activity. *Am J Physiol*. 1994;266(2 Pt 1):E161-170.
80. Wang YH, Chen SY, Wang TD, Hwang BS, Huang TS, Su TC. The relationships among serum glucose, albumin concentrations and carotid atherosclerosis in men with spinal cord injury. *Atherosclerosis*. 2009;206(2):528-534.
81. Bluvshstein V, Korczyn AD, Pinhas I, Vered Y, Gelernter I, Catz A. Insulin resistance in tetraplegia but not in mid-thoracic paraplegia: Is the mid-thoracic spinal cord involved in glucose regulation? *Spinal Cord*. 2011;49(5):648-652.
82. Segal JL, Thompson JF, Tayek JA. Effects of long-term 4-aminopyridine therapy on glucose tolerance and glucokinetics in patients with spinal cord injury. *Pharmacotherapy*. 2007;27(6):789-792.
83. Palmer JP, Henry DP, Benson JW, Johnson DG, Ensink JW. Glucagon response to hypoglycemia in sympathectomized man. *J Clin Invest*. 1976;57(2):522-525.
84. Aksnes AK, Hjeltne N, Wahlstrom EO, Katz A, Zierath JR, Wallberg Henriksson H. Intact glucose transport in morphologically altered denervated skeletal muscle from quadriplegic patients. *Am J Physiol Endocrinol Metab*. 1996;271(3):E593-E600.
85. Karlsson AK. Insulin resistance and sympathetic function in high spinal cord injury. *Spinal Cord*. 1999;37(7):494-500.
86. Gorgey AS, Gater DR. A preliminary report on the effects of the level of spinal cord injury on the association between central adiposity and metabolic profile. *PM&R*. 2011;3(5):440-446.
87. Okul I, Unalan H, Erhan B, Damci T, Uludag M. Glucose intolerance, insulin resistance, and C peptide levels in patients with spinal cord injury. *Neurosurg Q*. 2007;17(3):170-174.
88. Hjeltne N, Galuska D, Bjornholm M, et al. Exercise-induced overexpression of key regulatory proteins involved in glucose uptake and metabolism in tetraplegic persons: Molecular mechanism for improved glucose homeostasis. *FASEB J*. 1998;12(15):1701-1712.
89. Shulman GI. Cellular mechanisms of insulin resistance. *J Clin Invest*. 2000;106(2):171-176.
90. DeFronzo RA, Gunnarsson R, Bjorkman O, Olsson M, Wahren J. Effects of insulin on peripheral and splanchnic glucose-metabolism in noninsulin-dependent (Type-II) diabetes-mellitus. *J Clin Invest*. 1985;76(1):149-155.
91. Bouche C, Serdy S, Kahn CR, Goldfine AB. The cellular fate of glucose and its relevance in type 2 diabetes. *Endocr Rev*. 2004;25(5):807-830.
92. Kahn SE, Prigeon RL, McCulloch DK, et al. The contribution of insulin-dependent and insulin-independent glucose-uptake to intravenous glucose-tolerance in healthy-human subjects. *Diabetes*. 1994;43(4):587-592.
93. Elder CP, Apple DF, Bickel CS, Meyer RA, Dudley GA. Intramuscular fat and glucose tolerance after spinal cord injury - a cross-sectional study. *Spinal Cord*. 2004;42(12):711-716.
94. Cowan RE, Nash MS. Cardiovascular disease, SCI and exercise: Unique risks and focused countermeasures. *Disabil Rehabil*. 2010;32(26):2228-2236.
95. Kemp BJ, Spungen AM, Adkins RH, Krause JS, Bauman WA. The relationships among serum lipid levels, adiposity, and depressive symptomatology in persons aging with spinal cord injury. *J Spinal Cord Med*. 2000;23(4):216-220.
96. Bauman WA, Kahn NN, Grimm DR, Spungen AM. Risk factors for atherogenesis and cardiovascular autonomic function in persons with spinal cord injury. *Spinal Cord*. 1999;37(9):601-616.
97. Bauman WA, Spungen AM, Raza M, et al. Coronary artery disease: Metabolic risk factors and latent disease in individuals with paraplegia. *Mt Sinai J Med*. 1992;59(2):163-168.
98. Cragg JJ, Noonan VK, Krassioukov A, Borisoff J. Cardiovascular disease and spinal cord injury: Results from a national population health survey. *Neurology*. 2013;81(8):723-728.
99. Gilbert O, Croffoot JR, Taylor AJ, Nash M, Schomer K, Groah S. Serum lipid concentrations among persons with spinal cord injury - A systematic review and meta-analysis of the literature. *Atherosclerosis*. 2014;232(2):305-312.
100. Laclaustra M, Van den Berg ELM, Hurtado-Roca Y, Castellote JM. Serum lipid profile in subjects with traumatic spinal cord injury. *PloS One*. 2015;10(2).
101. Nash MS, Jacobs PL, Mendez AJ, Goldberg RB. Circuit resistance training improves the atherogenic lipid profiles of persons with chronic paraplegia. *J Spinal Cord Med*. 2001;24(1):2-9.
102. Jaye M, Krawiec J. Endothelial lipase and HDL metabolism. *Curr Opin Lipidol*. 2004;15(2):183-189.
103. Bravo EL. Metabolic factors and the sympathetic nervous system. *Am J Hypertens*. 1989;2(12):S339-S344.
104. Manns PJ, McCubbin JA, Williams DP. Fitness, inflammation, and the metabolic syndrome in men with paraplegia. *Arch Phys Med Rehabil*. 2005;86(6):1176-1181.

105. Segal JL, Gonzales E, Yousefi S, Jamshidipour L, Brunnemann SR. Circulating levels of IL-2R, ICAM-1, and IL-6 in spinal cord injuries. *Arch Phys Med Rehabil.* 1997;78(1):44-47.
106. Jin WJ, Sun GS, Marchadier D, Octaviani E, Glick JM, Rader DJ. Endothelial cells secrete triglyceride lipase and phospholipase activities in response to cytokines as a result of endothelial lipase. *Circulation Res.* 2003;92(6):644-650.
107. Morin CL, Schlaepfer IR, Eckel RH. Tumor-necrosis-factor- α eliminates binding of Nf-Y and an octamer-binding protein to the lipoprotein-lipase promoter in 3T3-L1 adipocytes. *J Clin Invest.* 1995;95(4):1684-1689.
108. Feingold KR, Memon RA, Moser AH, Shigenaga JK, Grunfeld C. Endotoxin and interleukin-1 decrease hepatic lipase mRNA levels. *Atherosclerosis.* 1999;142(2):379-387.
109. Barter P. Effects of inflammation on high-density lipoproteins. *Arterioscl Thromb Vas.* 2002;22(7):1062-1063.
110. Bausserman LL, Bernier DN, Mcadam KPWJ, Herbert PN. Serum amyloid-a and high-density lipoproteins during the acute phase response. *Eur J Clin Invest.* 1988;18(6):619-626.
111. Nash MS, DeGroot J, Martinez-Arizala A, Mendez AJ. Evidence for an exaggerated postprandial lipemia in chronic paraplegia. *J Spinal Cord Med.* 2005;28(4):320-325.
112. Emmons RR, Garber CE, Cirigliaro CM, et al. The influence of visceral fat on the postprandial lipemic response in men with paraplegia. *J Am College Nutr.* 2010;29(5):476-481.
113. Karpe F, Dickmann JR, Frayn KN. Fatty acids, obesity, and insulin resistance: Time for a reevaluation. *Diabetes.* 2011;60(10):2441-2449.
114. Lopez-Miranda J, Perez-Martinez P, Marin C, Moreno JA, Gomez P, Perez-Jimenez F. Postprandial lipoprotein metabolism, genes and risk of cardiovascular disease. *Curr Opin Lipidol.* 2006;17(2):132-138.
115. Pastromas S, Terzi AB, Tousoulis D, Koulouris S. Postprandial lipemia: An under-recognized atherogenic factor in patients with diabetes mellitus. *Int J Cardiol.* 2008;126(1):3-12.
116. Blackburn P, Lamarche B, Couillard C, et al. Postprandial hyperlipidemia: Another correlate of the "hypertriglyceridemic waist" phenotype in men. *Atherosclerosis.* 2003;171(2):327-336.
117. Thompson WR GN, Pescatello LS. *ACSM's Guidelines for Exercise Testing and Prescription.* 9th ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins; 2010.
118. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334-1359.
119. Ginis KA, Hicks AL, Latimer AE, et al. The development of evidence-informed physical activity guidelines for adults with spinal cord injury. *Spinal Cord.* 2011;49(11):1088-1096.
120. Association APT. *Physical Fitness for Individuals with Spinal Cord Injury.* Alexandria, VA: American Physical Therapy Association; 2015.
121. Nash MS. Exercise as a health-promoting activity following spinal cord injury. *J Neural Phys Ther.* 2005;29(2):87-103,106.
122. Nash MS, Cowan RE, Kressler J. Evidence-based and heuristic approaches for customization of care in cardiometabolic syndrome after spinal cord injury. *J Spinal Cord Med.* 2012;35(5):278-292.
123. Devillard X, Rimaud D, Roche F, Calmels P. Effects of training programs for spinal cord injury. *Ann Readapt Med Phys.* 2007;50(6):490-498,480-499.
124. Jacobs PL, Nash MS. Exercise recommendations for individuals with spinal cord injury. *Sports Med.* 2004;34(11):727-751.
125. Myers J, Lee M, Kiratli J. Cardiovascular disease in spinal cord injury: An overview of prevalence, risk, evaluation, and management. *Am J Phys Med Rehabil.* 2007;86(2):142-152.
126. Cragg JJ, Stone JA, Krassioukov AV. Management of cardiovascular disease risk factors in individuals with chronic spinal cord injury: An evidence-based review. *J Neurotrauma.* 2012;29(11):1999-2012.
127. Myers J, Kiratli BJ, Jaramillo J. The cardiometabolic benefits of routine physical activity in persons living with spinal cord injury. *Curr Cardiovasc Risk Rep.* 2012;6(4):323-330.
128. Haisma JA, van der Woude LH, Stam HJ, Bergen MP, Sluis TA, Bussmann JB. Physical capacity in wheelchair-dependent persons with a spinal cord injury: A critical review of the literature. *Spinal Cord.* 2006;44(11):642-652.
129. Hicks AL, Martin Ginis KA, Pelletier CA, Ditor DS, Foulon B, Wolfe DL. The effects of exercise training on physical capacity, strength, body composition and functional performance among adults with spinal cord injury: A systematic review. *Spinal Cord.* 2011;49(11):1103-1127.
130. Valent L, Dallmeijer A, Houdijk H, Talsma E, van der Woude L. The effects of upper body exercise on the physical capacity of people with a spinal cord injury: A systematic review. *Clin Rehabil.* 2007;21(4):315-330.
131. Stewart MW, Melton-Rogers SL, Morrison S, Figoni SF. The measurement properties of fitness measures and health status for persons with spinal cord injuries. *Arch Phys Med Rehabil.* 2000;81(4):394-400.
132. Kilkens OJ, Dallmeijer AJ, Nene AV, Post MW, van der Woude LH. The longitudinal relation between physical capacity and wheelchair skill performance during inpatient rehabilitation of people with spinal cord injury. *Arch Phys Med Rehabil.* 2005;86(8):1575-1581.
133. Dallmeijer AJ, van der Woude LHV. Health related functional status in men with spinal cord injury: Relationship with lesion level and endurance capacity. *Spinal Cord.* 2001;39(11):577-583.
134. DiCarlo SE. Effect of arm ergometry training on wheelchair propulsion endurance of individuals with quadriplegia. *Phys Ther.* 1988;68(1):40-44.
135. Warburton DER, Eng JJ, Krassioukov A, Sproule S, the SRT. Cardiovascular health and exercise

- rehabilitation in spinal cord injury. *Top Spinal Cord Inj Rehabil.* 2007;13(1):98-122.
136. Hooker SP, Wells CL. Effects of low- and moderate-intensity training in spinal cord-injured persons. *Med Sci Sports Exerc.* 1989;21(1):18-22.
  137. Hjeltne N, Wallberg-Henriksson H. Improved work capacity but unchanged peak oxygen uptake during primary rehabilitation in tetraplegic patients. *Spinal Cord.* 1998;36(10):691-698.
  138. de Groot S, van der Scheer JW, Bakkum AJ, et al. Wheelchair-specific fitness of persons with a long-term spinal cord injury: Cross-sectional study on effects of time since injury and physical activity level. *Disabil Rehabil.* 2016;38(12):1180-1186.
  139. Jacobs PL, Nash MS, Rusinowski JW. Circuit training provides cardiorespiratory and strength benefits in persons with paraplegia. *Med Sci Sports Exerc.* 2001;33(5):711-717.
  140. Nash MS, van de Ven I, van Elk N, Johnson BM. Effects of circuit resistance training on fitness attributes and upper-extremity pain in middle-aged men with paraplegia. *Arch Phys Med Rehabil.* 2007;88(1):70-75.
  141. Janssen TW, van Oers CA, van Kamp GJ, TenVoorde BJ, van der Woude LH, Hollander AP. Coronary heart disease risk indicators, aerobic power, and physical activity in men with spinal cord injuries. *Arch Phys Med Rehabil.* 1997;78(7):697-705.
  142. El-Sayed MS, Younesian A. Lipid profiles are influenced by arm cranking exercise and training in individuals with spinal cord injury. *Spinal Cord.* 2005;43(5):299-305.
  143. de Groot PC, Hjeltne N, Heijlboer AC, Stal W, Birkeland K. Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. *Spinal Cord.* 2003;41(12):673-679.
  144. Jacobs PL, Mahoney ET, Nash MS, Green BA. Circuit resistance training in persons with complete paraplegia. *J Rehabil Res Dev.* 2002;39(1):21-28.
  145. Pelletier C, de Zepetnek JT, MacDonald M, Hicks A. A 16-week randomized controlled trial evaluating the physical activity guidelines for adults with spinal cord injury. *Spinal Cord.* 2015;53(5):363-367.
  146. Buchholz AC, Martin Ginis KA, Bray SR, et al. Greater daily leisure time physical activity is associated with lower chronic disease risk in adults with spinal cord injury. *Appl Physiol Nutr Metabol.* 2009;34(4):640-647.
  147. Borghouts LB, Keizer HA. Exercise and insulin sensitivity: A review. *Int J Sports Med.* 2000;21(1):1-12.
  148. Mosher PE, Nash MS, Perry AC, LaPerriere AR, Goldberg RB. Aerobic circuit exercise training: Effect on adolescents with well-controlled insulin-dependent diabetes mellitus. *Arch Phys Med Rehabil.* 1998;79(6):652-657.
  149. D'Oliveira GL, Figueiredo FA, Passos MC, Chain A, Bezerra FF, Koury JC. Physical exercise is associated with better fat mass distribution and lower insulin resistance in spinal cord injured individuals. *J Spinal Cord Med.* 2014;37(1):79-84.
  150. Bakkum AJ, Paulson TA, Bishop NC, et al. Effects of hybrid cycle and handcycle exercise on cardiovascular disease risk factors in people with spinal cord injury: A randomized controlled trial. *J Rehabil Med.* 2015;47(6):523-530.
  151. Kim DI, Lee H, Lee BS, Kim J, Jeon JY. Effects of a 6-week indoor hand-bike exercise program on health and fitness levels in people with spinal cord injury: A randomized controlled trial study. *Arch Phys Med Rehabil.* 2015;96(11):2033-2040 e2031.
  152. Tanhoffer RA, Tanhoffer AI, Raymond J, Hills AP, Davis GM. Exercise, energy expenditure, and body composition in people with spinal cord injury. *J Phys Act Health.* 2014;11(7):1393-1400.
  153. Martin Ginis KA, Jorgensen S, Stapleton J. Exercise and sport for persons with spinal cord injury. *PM R.* 2012;4(11):894-900.
  154. Feasel S GS. The impact of diet on cardiovascular disease risk in individuals with spinal cord injury. *Top Spinal Cord Inj Rehabil.* 2009;14(3):56-68.
  155. Gorgey AS, Mather KJ, Cupp HR, Gater DR. Effects of resistance training on adiposity and metabolism after spinal cord injury. *Med Sci Sports Exerc.* 2012;44(1):165-174.
  156. Haisma JA, Post MW, van der Woude LH, et al. Functional independence and health-related functional status following spinal cord injury: A prospective study of the association with physical capacity. *J Rehabil Med.* 2008;40(10):812-818.
  157. Duran FS, Lugo L, Ramirez L, Eusse E. Effects of an exercise program on the rehabilitation of patients with spinal cord injury. *Arch Phys Med Rehabil.* 2001;82(10):1349-1354.