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INVITED REVIEW

Cardiovascular Disease in Spinal Cord Injury

An Overview of Prevalence, Risk, Evaluation, and Management

ABSTRACT

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Cardiovascular disease is a growing concern for the spinal cord–injured (SCI) population. For long-term SCI, morbidity and mortality from cardiovascular causes now exceeds that caused by renal and pulmonary conditions, the primary causes of mortality in previous decades. Although risk estimates commonly used for ambulatory individuals have not been established from follow-up studies in SCI, nearly all risk factors tend to be more prevalent in SCI subjects compared with ambulatory subjects. These risks include a greater prevalence of obesity, lipid disorders, metabolic syndrome, and diabetes. Daily energy expenditure is significantly lower in SCI individuals, not only because of a lack of motor function, but also because of a lack of accessibility and fewer opportunities to engage in physical activity. Autonomic dysfunction caused by SCI is also associated with several conditions that contribute to heightened cardiovascular risk, including abnormalities in blood pressure, heart rate variability, arrhythmias, and a blunted cardiovascular response to exercise that can limit the capacity to perform physical activity. Thus, screening, recognition, and treatment of cardiovascular disease should be an essential component of managing individuals with SCI, and judicious treatment of risk factors can play an important role in minimizing the incidence of cardiovascular disease in these individuals. This article reviews the cardiovascular consequences of chronic SCI, including the prevalence of cardiovascular disease and risk factors unique to these individuals, and provides a synopsis of management of cardiovascular disease in this population.

Key Words: Cardiovascular Disease, Spinal Cord Injury, Renal, Pulmonary

Spinal cord injury (SCI) is a serious medical condition with considerable functional, psychological, and socioeconomic sequelae. Although there have been major advances in neurological treatment for SCI, the mortality rate for this condition remains high relative to ambulatory populations.[1–3] Historically, respiratory and renal conditions have been the most prevalent comorbidities in the SCI population, and they remain important causes of mortality. However,

data published in recent years suggest that cardiovascular disease (CVD) has emerged as the leading cause of mortality in chronic SCI.[4] Morbidity from cardiovascular causes, particularly coronary artery disease (CAD), is high relative to ambulatory subjects, and CAD tends to occur earlier in SCI individuals than among ambulatory populations.[3–5] A major contributor to the heightened risk of CVD in SCI is the fact that risk factors, including hypertension, hyperlipidemia, obesity, and diabetes, have been shown to be comparatively high among individuals with SCI.[5–9] The recognition and treatment of CVD is an emerging clinical challenge in this population.

An additional contributing factor to the high cardiovascular morbidity and mortality in SCI is the sedentary lifestyle and reduced physical function associated with loss of motor function.[10,11] SCI is also characterized by a disruption of the normal autonomic cardiovascular control mechanisms,[12,13] and there is growing recognition that this further contributes to cardiovascular risk.[12,14] The latter occurs as a result of a variety of physiologic changes related to cardiovascular control that are observed in SCI, including loss of normal regulation of the peripheral vasculature, autonomic dysreflexia (AD), and a higher prevalence of cardiac rhythm disturbances.[12–15] The major cardiovascular concerns associated with SCI are outlined in Table 1. The purpose of this review article is to provide an overview of the cardiovascular consequences of chronic SCI, including the prevalence of CVD and risk factors unique to these individuals, and a synopsis of management of CVD in this population.

TABLE 1 Cardiovascular concerns in spinal cord injury

- Higher prevalence of cardiovascular disease
- Greater morbidity and mortality from cardiovascular causes
- Heightened cardiovascular risk factors:

Low high-density lipoprotein cholesterol
High total cholesterol and low-density lipoprotein
Elevated C-reactive protein
Higher prevalence of obesity and greater visceral adipose tissue
Increased rate of smoking
Physical inactivity
Higher prevalence of insulin resistance, diabetes, and metabolic syndrome

- Blood pressure abnormalities (orthostatic hypotension, autonomic dysreflexia)
- Deep vein thrombosis, thromboembolic events
- Rhythm disturbances

Bradyarrhythmias, particularly in the acute phase, (e.g., bradycardia, A-V block, cardiac arrest)
Reduced heart rate variability

- Blunted cardiovascular response to exercise

PREVALENCE OF CVD IN SCI

Precise estimates of the prevalence of CVD in SCI are complicated by the comparatively high prevalence of latent heart disease and by the misclassification of CVD attributable to concomitant disorders.[1,4,7,16,17] Nevertheless, studies are consistent in demonstrating a higher prevalence of CVD among SCI individuals compared with that in ambulatory populations.[4,5,16,18,19] Groah et al.[19] studied 545 SCI subjects surviving at least 25 yrs after injury and observed that the risk of developing CVD was associated with both the level and extent of injury. Tetraplegic level of injury was associated with a 16% higher risk of all CVD (CAD, hypertension, cerebrovascular disease, valvular disease, and dysrhythmias) and a fivefold increase in cerebrovascular disease, but paraplegic subjects had a 70% greater risk of CAD. Complete injury conferred a 44% greater risk of overall CVD. Bauman and colleagues[16] reported that the prevalence of silent ischemia in a middle-aged (mean 52 yrs) cohort of paraplegic subjects was 65% based on nuclear imaging. Other studies have reported lesser, but nevertheless substantial, prevalence rates of asymptomatic CVD in SCI populations (ranging from approximately 25% to more than 50%).[5,10,20] The prevalence rates of symptomatic CVD have similarly ranged from approximately 30% to more than 50%.[10,12,18] In contrast, among age-matched able-bodied populations, the prevalence of CVD is typically reported to be in the range of 5–10%.[21]

In terms of mortality from cardiovascular causes, cohorts of subjects with chronic SCI have been reported to have both higher cardiovascular mortality rates and mortality occurring at earlier ages compared with able-bodied subjects. This is particularly true among subjects with SCI of long duration. Whiteneck and colleagues[1] reported that CVD was the leading cause of mortality in persons with SCI of more than 30-yr duration; approximately half of SCI subjects in this cohort died of cardiovascular causes. In an analysis of >28,000 SCIs occurring between 1973 and 1998 among subjects admitted to two SCI health care systems, heart disease was the leading cause of mortality after the first year of injury.[22] Although morbidity and mortality rates have not been established with certainty, the available data suggest that major efforts need to be made to identify risk factors for CVD that are modifiable, and appropriate intervention strategies should be developed to reduce these rates of cardiovascular morbidity and mortality in persons with SCI.

RISK FACTORS FOR CVD IN SCI

A heightened prevalence of virtually all the major risk factors for CVD exists for persons with SCI, and this is one of the major challenges for clinicians who treat this condition. An algorithm for guiding CVD risk management, modified from the American Heart Association Guidelines for Primary Prevention of Cardiovascular Disease and Stroke,[23] is presented in Table 2. Although algorithms for reducing CVD risk have not been designed specifically for SCI, these strategies can be generally used to guide risk reduction for those at risk for CVD.

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Diabetes/Metabolic Syndrome

Diabetes and metabolic syndrome are two closely linked conditions associated with CVD risk and are considered by the American Heart Association to be major risk factors for heart disease. Metabolic syndrome is a prediabetic state that has been strongly linked to both heart disease and diabetes mellitus[24–26]; its presence roughly doubles the risk of CVD mortality. The metabolic syndrome is closely associated with obesity (increased waist circumference), atherogenic dyslipidemia (high triglycerides; low high-density lipoprotein [HDL] cholesterol; increased small, dense low-density lipoprotein [LDL] cholesterol; and increased apolipoprotein B), increased blood pressure, insulin resistance (hyperinsulinemia, glucose intolerance, increased uric acid), a prothrombotic state (increased plasminogen activator inhibitor [PAI-1], increased blood viscosity, increased plasma fibrinogen), and proinflammatory conditions (increased C-reactive protein, or CRP). The prevalence of the metabolic syndrome and its individual components have been shown to be high among individuals with SCI.[6,12,27,28] Lee and colleagues[6] observed that the metabolic syndrome was present in 23% of SCI individuals (roughly double that of populations of similar age) and that prediabetes and cardiovascular risk scores by Framingham criteria were elevated relative to those reported among ambulatory populations.

The use of ambulatory guidelines for the determination of metabolic syndrome in the SCI population may not be appropriate in the context of the anthropometric and physiologic changes associated with chronic SCI. In particular, the use of waist circumference may not adequately reflect abdominal adipose tissue or abdominal visceral adipose tissue in SCI individuals, given the particularly sedentary nature of chronic SCI. In some studies, body mass index has been substituted for waist circumference; however, body mass index often underestimates body fat in individuals with SCI.[29] Although it is assumed that the sedentary lifestyle imposed by chronic SCI increases central obesity,[5] there is no current consensus for a clinically useful measure of obesity in the SCI population. Other criteria for determination of the metabolic syndrome have not been adequately defined for the SCI population. Although persons with SCI have generally been found to have greater lipid abnormalities compared with able-bodied individuals, it is not clear how this affects their prediabetic status. In addition, hypertension and glucose metabolism require further examination as components of the metabolic syndrome in persons with SCI.

Lipid Disorders in SCI

Abnormal lipid values have long been established as risk factors for the development of diabetes and heart disease.[30] After SCI, there is a tendency toward elevated LDL cholesterol and total cholesterol as well as lower HDL cholesterol levels compared with able-bodied persons.[8,12,26–28] In acute SCI, lipid levels are generally depressed and normalize within the first year.[31] However, after the first year after injury, persons with SCI tend to develop elevated LDL cholesterol and total cholesterol levels and continue to maintain lowered HDL cholesterol levels compared with able-bodied populations.[32] Persons with tetraplegia tend to have a greater number of lipid abnormalities than their paraplegic counterparts.[9,33] The greater degree of dyslipidemia found in the SCI population contributes significantly to their increased CVD risk. Abnormal lipids are generally modifiable with changes in physical activity and diet along with the use of statins; however, among persons with SCI, the degree of dyslipidemia is more strongly linked to the duration of injury than to diet.[34] This suggests that the metabolic changes and physical inactivity associated with SCI may have significant consequences for the prevalence of dyslipidemia in this population.

Inflammatory Markers

Inflammation is increasingly recognized to have an important role in the development of CVD. The most widely studied inflammatory marker, CRP, has been found to be elevated in both acute and chronic SCI. Elevated CRP is observed in SCI individuals both with and without urinary tract infections, suggesting that it may be caused more by some underlying disease state than by the injury itself.[35] To date, only one study has investigated the relationship between CRP and CVD risk in persons with SCI. In that study, CRP was significantly associated with the presence of other well-known CVD risk factors, including multiple lipid abnormalities, metabolic syndrome, insulin resistance, and elevated Framingham risk.[6] The mean high-

TABLE 2 Guide to primary prevention of cardiovascular diseases

Risk Intervention	Recommendations	
Smoking:	Ask about smoking status as part of routine evaluation. Reinforce nonsmoking status.	
Goal		
Complete cessation	Strongly encourage patient and family to stop smoking. Provide counseling, nicotine replacement, and formal cessation programs as appropriate.	
Blood pressure control:	Measure blood pressure in all adults at least every 2.5 yrs.	
Goal	Promote lifestyle modification: weight control, physical activity, moderation in alcohol intake, moderate sodium restriction. If blood pressure is around 140/190 mm Hg after 3 months of life-habit modification, or if initial blood pressure is greater than 160/100 mm Hg, add blood pressure medication; individualize therapy to patient's other requirements and characteristics.	
<140/90 mm Hg		
Cholesterol management	Ask about dietary habits as part of routine evaluation. Measure total and HDL cholesterol in all adults 20 yrs or older, and assess positive and negative risk factors at least every 5 yrs.	
Primary goal		
LDL <160 mg/dl if zero or one risk factors, or LDL <130 mg/dl if more than two risk factors	For all persons: promote AHA Step I diet (30% fat, <10% saturated fat, <300 mg/dl cholesterol), weight control, and physical activity.	
Secondary goals		
HDL >35 mg/dl		
TG <200 mg/dl		
	Measure LDL if total cholesterol is around 240 mg/dl or >200 mg/dl with two or more risk factors or if HDL <35 mg/dl	
	If LDL: >160 mg/dl with zero or one risk factor, or >130 mg/dl on two occasions with more than two risk factors; then —Start Step II diet (<30% fat, <7% saturated fat, <200 mg/dl cholesterol) and weight control. —Rule out secondary causes of high LDL (LFTs, TFTs, UA).	Risk factors: age (men >45 yrs, women >55 yrs or postmenopausal), hypertension, diabetes, smoking, HDL <35 mg/dl, family history of CHD in first-degree relatives (in male relatives <55 yrs, female relatives <65 yrs). If HDL >60 mg/dl, subtract one risk factor from the number of positive risk factors.
	If LDL: >160 mg/dl plus two risk factors; or >190 mg/dl; or >220 mg/dl in men <35 yrs; or in premenopausal women; then —Consider adding drug therapy to diet therapy for LDL levels greater than those listed above that persist despite Step II diet.	
	Suggested drug therapy for high LDL levels (>160 mg/dl) (drug selection priority modified according to TG level)	

TABLE 2 Continued

Risk Intervention	Recommendations			
	TG <200 mg/dl	TG 200–400 mg/dl	TG >400 mg/dl	**If HDL <35 mg/dl:** Emphasize weight management and physical activity, avoidance of cigarette smoking. Niacin raises HDL. Consider niacin if patient has more than two risk factors and high LDL (except patients with diabetes).
	Statin Resin Niacin	Statin Niacin	Consider combined drug therapy (niacin, fibrates, statin)	
	If LDL goal not achieved, consider combination drug therapy.			
Physical activity:	Ask about physical activity status and exercise habits as part of routine evaluation. Encourage 30 minutes of moderate-intensity dynamic exercise three to five times per week as well as increased physical activity in daily life habits for persons who are inactive.			
Goal Increase amount. Exercise regularly five to seven times per week for 30 minutes.	Encourage regular exercise to improve conditioning and to optimize fitness level. Advise medically supervised programs for those with low functional capacity and/or comorbidities. Promote environmental factors conducive to health (i.e., golf courses that permit walking).			
Weight management: Goal Achieve and maintain desirable weight (BMI 21–25 kg/m^2).	Measure patient's weight and height, BMI, and waist-to-hip ratio at each visit as part of routine evaluation. Start weight management and physical activity as appropriate. Desirable BMI range: 21–25 kg/m^2. BMI of 25 kg/m^2 corresponds to percentage desirable body weight of 110%; desirable waist-to-hip ratio for men, <0.9; for middle-aged and elderly women, <0.8.			
Diabetes management: Goals: Normal fasting plasma glucose (<110 mg/dL) and normal HbA1c (<7%)	Initiate appropriate hypoglycemic therapy. First step is diet and exercise. Second step is usually hypoglycemic therapy. Third step therapy is insulin. Treat other risk factors more aggressively (e.g., change BP goal to <130/80 mm Hg and LDL cholesterol goal to <100 mg/dl).			

TG, triglycerides; LFTs, liver function tests; TFTs, thyroid function tests; UA, uric acid; CHD, coronary heart disease; BMI, body mass index; BP, blood pressure; HDL, high-density lipoprotein, LDL, low-density lipoprotein.

Modified from Pearson et al.[23]

sensitivity CRP level in these subjects (2.37 ± 2.1 mg/liter) placed them in a high-risk group on the basis of quintiles established for ambulatory individuals. However, no follow-up studies exist that have established the role of CRP in the development of atherosclerosis and CVD in SCI.

Physical Inactivity in SCI

The reduced physical function associated with SCI underlies a greater sedentary lifestyle and lower energy expenditure. Using a variety of techniques to quantify daily energy expenditure, studies have shown that SCI individuals have lower resting metabolic rates and, on average, expend significantly less daily energy than ambulatory subjects.[5,36–38] The extent to which energy expenditure is reduced is proportional to the muscle mass that has been paralyzed from loss of central control, and has been shown to range from approximately 10% to more than 50%.[36–38] This underlies a higher proportion of fat mass and a greater prevalence of obesity, contributing to a variety of related metabolic abnormalities associated with inactivity, including insulin resistance, lower HDL levels, and greater susceptibility to vascular inflammation.[6,9,10–12]

Chronic immobilization associated with SCI also leads to a number of skeletal-muscle metabolic and structural abnormalities. Specific alterations in morphologic and contractile properties of skeletal muscle with chronic SCI have been shown, using electromyography studies, biopsy, and magnetic resonance imaging. These alterations include lower protein content, an increase in myosin heavy-chain isoforms, reduced fiber cross-sectional area, and reduced force and fatigue characteristics with functional electrical stimulation.[39–44] The inability to ambulate the lower limbs also contributes to the risk of deep vein thrombosis,[45] in addition to the above-mentioned heightened prevalence of insulin resistance and low HDL levels.[6,9,33]

Recent studies have shown that many of the metabolic and skeletal-muscle abnormalities associated with SCI can be partially reversed by endurance training with upper-body arm ergometry, functional electrical-stimulation training of the lower limbs, or their combination.[5,10,11] Swimming, supported treadmill ambulation, and other adapted modes of training have also been used.[11,46,47] Peak VO_2 has been shown to increase to a degree that is similar to or slightly less than that of ambulatory subjects, for instance, on the order of 10–20% after varying periods of training. These increases seem to be inversely proportional to the level of injury.[11,48,49] Regular exercise has also been shown to favorably affect lipid profiles in SCI.[50,51] Functional electrical-stimulation training of the lower limbs has been shown to reverse muscle atrophy, increase muscle mass, and increase isometric strength and endurance.[52–55] In some studies, functional electrical-stimulation training has also improved lower-limb circulation and vasodilatory capacity,[56,57] body composition,[53,54] and insulin resistance[58] in subjects with varying levels of SCI. However, ready access to these sorts of training regimens is lacking in the general SCI population.

CARDIOVASCULAR CONSEQUENCES OF AUTONOMIC DYSFUNCTION

Autonomic nervous system dysfunction causes a disruption of normal cardiovascular homeostasis, which itself increases the risk of CVD, particularly in higher-level injuries. Cardiovascular problems directly associated with autonomic dysfunction that have been extensively described in SCI include loss of vasomotor control leading to orthostatic hypotension, AD, reflex bradycardia and, in extreme cases, cardiac arrest. Other factors that increase the risk for CVD that are attributable to loss of supraspinal control include reduced heart rate variability (HRV); attenuated cardiovascular responses to activity, including reduced cardiac contractility; and changes to the skin microcirculation.[12–14,59]

Blood Pressure Abnormalities

Arterial blood pressure is typically chronically low in individuals with SCI because of a reduction in sympathetic nervous system activity below the level of injury. Hypotension at rest and, in particular, orthostatic hypotension, contribute to hemodynamic instability in SCI.[60–62] Orthostatic hypotension is characterized by dizziness, weakness, blurred vision, and syncope when shifting from the supine to the upright sitting position. The normal hemodynamic response to standing is an increase in heart rate and contractility via activation of autonomic reflexes through the carotid and aortic baroreceptors. This causes vagal inhibition and sympathetic stimulation, resulting in an increase in blood pressure. Baroreflex control of vascular tone is often absent in SCI, particularly in higher-level injuries, among whom orthostatic hypotension is common.[60–62]

AD is a far more serious hemodynamic consequence of SCI; in extreme cases, it can be life threatening. AD is characterized by sympathetic hyperactivity, causing severe vasoconstriction and hypertension below the level of the lesion. Cerebrovascular accidents secondary to AD have been described and are thought to be an important cause of mortality in the SCI population.[63] AD has been estimated to occur between 48 and 90% of individuals who are injured at level T_6 and above.[64–66] With AD, vasomotor reflexes above the level of injury attempt to lower blood pressure by increas-

ing parasympathetic stimulation to the heart via the vagus nerve, which results in vasodilation, light-headedness, profuse sweating, and skin flushing. Because AD can trigger severe cardiovascular reactions, it represents a medical emergency that requires immediate treatment. Cardiovascular consequences of AD can include periods of severe bradycardia or tachycardia, a hypertensive emergency (severe, sustained hypertension causing significant organ damage or impairment), left ventricular failure, myocardial ischemia, or serious rhythm disturbances.[63,64] Treatment requires immediate removal of the precipitating stimuli (most commonly, bladder distension) and pharmacologic stabilization of blood pressure.[67]

HRV

HRV describes the quantification of beat-to-beat variations of the R-R interval on the electrocardiogram, measured over a period of time ranging from a few minutes to 24 hrs. Its recent appeal can be attributed to the fact that it is simple to measure, is noninvasive, and is known to mirror sympathetic and parasympathetic nervous system balance. Numerous studies published in the last 10 yrs have documented that abnormal (reduced) HRV strongly predicts risk for cardiac events.[68–70] A great deal of research in recent years has employed HRV indices to assess autonomic balance in various chronic disease states, including neuromuscular disorders, neuropathy caused by diabetes, and SCI. SCI provides a good model for the application of HRV, because the interruption of efferent sympathetic pathways innervating the cardiovascular system disrupts the normal autonomic nervous system balance, which is reflected in altered HRV patterns. Several groups have observed an inverse association between the level and completeness of injury and autonomic dysfunction expressed using HRV.[71–73] These HRV findings reflect both parasympathetic downregulation and lessened sympathetic nervous input to the heart. In addition, they confirm that HRV is abnormal in persons with SCI relative to able-bodied individuals. Patterns of altered HRV have been suggested as useful in characterizing the physiology associated with injury level, and although this requires further study, these patterns may have diagnostic, prognostic, and therapeutic significance.

Cardiac Arrhythmias

High-level injuries are particularly prone to cardiac rhythm disturbances, which are most notable in the acute phase of injury.[15,59,74–76] Studies suggest that this is largely attributable to heightened sympathetic tone. Arrhythmias after SCI can range from benign to fatal. Bradyarrhythmias are common in the acute phase, including AV block; in fact, bradycardia was shown to occur in the vast majority of consecutive patients referred to a neurologic intensive care unit after SCI.[15] Lehmann and colleagues[15] observed that 16% of cervical-injured patients experienced cardiac arrest during the 14 days after hospital admission for acute injury. Rhythm disturbances are less of an issue among patients with chronic injuries. Marcus and colleagues[77] and Prakash et al.[78] observed that the occurrence of premature ventricular contractions on routine resting electrocardiograms was similar between ambulatory individuals and those with chronic SCI. A consistent finding, however, has been a higher prevalence of ST elevation in chronic SCI compared with ambulatory subjects, suggesting a shift in autonomic balance favoring vagal tone.[77,79]

Blunted Cardiovascular Responses to Activity

The magnitude of the physiologic response to exercise is diminished in SCI. Presumably, the attenuated cardiovascular and metabolic responses to activity reduce the well-known gains achieved by ambulatory subjects when exposed to regular physical activity.[5,10,11] Many studies have reported a strong inverse association between the level of injury and peak VO_2 achieved in SCI. Higher-level injuries generally prevent adequate sympathetic drive to increase heart rate beyond approximately 120–125 bpm.[80–83] However, even those with injuries below the level of sympathetic outflow (T_6) have lower stroke volumes at rest and attenuated cardiac output responses to exercise.[5,10,11,84,85] Loss of sympathetic tone also causes reduced myocardial preload and myocardial contractility, resulting in reduced stroke volume and cardiac output via the Frank–Starling mechanism. Chronically, these changes can lead to myocardial atrophy,[86,87] although this finding is not universal.[88]

The redistribution of blood flow to the active muscles during exercise that normally occurs in ambulatory individuals is largely absent after SCI, and, combined with the absence of intermittent contraction and relaxation of the skeletal muscles and absent or insufficient venoconstriction, venous return is inadequate, further blunting cardiac output. Blood tends to pool in the lower extremities, and compensatory increases in heart rate at rest and during exercise attempt to increase cardiac output in the presence of reduced ventricular volumes. Thus, arm ergometry exercise frequently results in hypotension because the metabolic demands of exercise are not matched by normal changes in peripheral vascular resistance. In addition, there is evidence that cardiac output may be lessened by intrinsically reduced cardiac contractility in SCI.[89,90] Ventilation is significantly im-

paired in tetraplegia because of paralysis of the intercostal and abdominal musculature, reduced pulmonary compliance, reduced diaphragmatic excursion, and blunted chemoreceptor stimulation.[82,91–93] This reduces inspiratory and expiratory pressures and all pulmonary function indices.[91–93] In combination, these factors contribute significantly to a reduced capacity to adapt appropriately to a bout of exercise, resulting in early fatigue, general avoidance of exertion, and deconditioning, which further contribute to CVD risk.[5,10,11]

CONSIDERATIONS FOR TREATMENT AND EVALUATION OF CVD IN SCI

In addition to the high prevalence of risk factors and their management, major cardiovascular considerations unique to chronic SCI include the detection and management of CAD, management of blood pressure (orthostatic hypotension and AD), and deep vein thrombosis. Although it has been demonstrated that SCI individuals are at higher risk for CVD (e.g., higher prevalence of lipid disorders, insulin resistance, and obesity, and reduced physical activity patterns), the extent to which multivariate models commonly used to estimate risk in ambulatory persons apply to SCI are unknown. Because of physiologic changes associated with SCI, the presence of SCI itself confers a higher risk of CVD. These changes include impaired autonomic responses that underlie abnormalities in resting heart rate, reduced HRV, reduced contractility, increased plasma rennin activity, and either heightened or blunted catecholamine production, depending on the level of injury and activity.[11,59,60,71–73,94–96] Although the latter factors are not usually the first issues considered when assessing risk for CVD, each can portend a higher risk for cardiac events.

Detection and Management of CAD

Diagnosis and management of CAD in SCI is complicated by the high prevalence of asymptomatic disease, known as silent ischemia.[16,17] Symptoms of CAD are frequently masked by the interruption of ascending afferent pain fibers in SCI; this presents a challenge in that lack of pain perception may cause CAD to be undetected and, therefore, untreated. Although silent ischemia is a concern in SCI, particularly in those with diabetes, the response to chest pain in general is, nevertheless, what should guide decisions regarding diagnostic studies. Traditional risk-factor scores used for ambulatory patients will likely predict a high probability for CAD in many SCI individuals, but the extent to which these scores relate to outcomes in SCI has not been explored. Thus, in general, careful treatment of risk factors is initially indicated rather than diagnostic testing.

The fact that persons with SCI are less likely to exert themselves to a level that would elicit angina also contributes to the underdiagnosis of CAD. In addition, diagnosis of CAD may be more difficult in SCI because exercise testing using arm ergometry is less likely to raise myocardial oxygen demand adequately to induce ischemic changes. Although arm ergometry has been shown to provide modest test characteristics in ambulatory patients (sensitivity of approximately 50%),[97] there are no studies specifically addressing this issue in large groups of SCI patients referred for exercise testing for clinical reasons. Therefore, the initial diagnostic test is most commonly pharmacologic stress, along with an echocardiographic or nuclear evaluation. These diagnostic tests may also be indicated for preoperative assessment in high-risk patients.

Treatment of CVD Risk Factors

Comprehensive CVD risk-factor evaluation should be an integral part of every clinical visit for individuals with SCI. Clinicians need to be cognizant of both the high prevalence of CVD risk markers as well as risks that are unique to this population, and they should treat these risks judiciously. Because regular physical activity has been shown to improve lipid profiles and other risk factors in SCI individuals,[5,10,11,50,51] physical activity should be strongly encouraged. Because of the physical and environmental limitations to physical activity participation for most persons with SCI, evaluation and follow-up by a physical therapist or exercise physiologist may help to optimize strategies to improve physical activity participation. Similarly, nutritional needs for persons with SCI are highly individualized because of wide differences in resting and daily energy expenditure. Routine consultation with a nutritionist may be helpful in the management of body weight and lipid profiles. This may be particularly important because dietary patterns of SCI individuals are generally poor.[98]

Deep Vein Thrombosis

Deep vein thrombosis (DVT) can occur frequently during either the acute or chronic phase of SCI. DVT is an important clinical concern throughout the rehabilitation period because mortality from pulmonary embolus is increased the year after injury. Even in the presence of anticoagulant therapy, the incidence of DVT in SCI has been shown to range from 7 to 100%, depending on age and severity of injury,[45,59] and 2.7% develop fatal pulmonary embolism.[99] Treatment focuses on prevention of pulmonary embolism and prevention of recurrent DVT.[100] After SCI, prophylactic treatment is usually recommended for 3 mos. Once the diagnosis of DVT is made, the usual treatment regimen includes low–molecular weight heparin initially for treatment of the thrombus, and pro-

AQ: 4 phylactic warfarin for at least 6 mos. INR should be maintained between 2 and 3.

Arrhythmias

Absence of sympathetic tone underlies a number of different rhythm disturbances, particularly in the acute phase of SCI. These can include severe bradycardia, A-V block, and cardiac arrest. Treatment for these often requires atropine administration, but in rare instances, pacemaker implantation may be required. In chronic SCI, arrhythmia management should be guided by the presence or absence of CVD, similar to ambulatory individuals. Presence of structural heart disease and poor left ventricular function are the most important factors in determining both prognosis and whether pharmacologic treatment is warranted. In the absence of CVD, drug therapy is not usually recommended for asymptomatic, isolated premature ventricular contractions, even when they are frequent. In the presence of CVD or arrhythmias causing symptoms, however, treatment initially involves beta blockade, with more serious rhythm disturbances requiring antiarrhythmic drugs, radiofrequency ablation, or, with life-threatening arrhythmias, an automatic implantable defibrillator.

SUMMARY

Abnormalities of the cardiovascular system have increasingly become a concern for treating individuals with SCI. CVD is now recognized as a leading cause of morbidity and mortality, and autonomic nervous system dysfunction underlies several cardiovascular irregularities that contribute to CVD. These include an accelerated decline in cardiovascular function with aging, and a heightened prevalence of virtually all the major risk factors for CVD. In the absence of follow-up trials specifically addressing the role of clinical and lifestyle factors on the incidence of CVD in SCI, algorithms developed for ambulatory individuals are applicable to SCI (Table 2). Better recognition of the importance of CVD in SCI, which is often asymptomatic and thus undertreated, has the potential to significantly reduce morbidity and mortality from CVD. Judicious treatment of lipids and insulin resistance and promotion of creative ways to enhance physical activity are important treatment components for this condition and will help temper the incidence of CVD for persons with SCI.

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