MOVE AGAIN PROGRAM: LITERATURE SEARCH

PART I

“EXERCISE AND SPINAL CORD INJURY”

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SUMMARY

Each year in Western Australia, about 40 new cases of spinal cord injury (SCI) are reported. The majority are transport and work-related, with a smaller proportion from falls and sporting accidents. Young males present most frequently, and there is an increasing proportion due to falls in older people. The damage to the spinal cord most frequently results in tetraplegia (upper and lower limbs affected), and a smaller proportion with paraplegia (lower limbs affected).

SCI results in a wide range of impairments depending on the spinal level and the completeness of the lesion. These include sensory and motor loss, muscle spasm, reduced control of autonomic systems such as respiration, cardiovascular responsiveness, bladder, bowel and sexual function, and energy metabolism. Long-term secondary health problems such as obesity, diabetes and cardiovascular disease are associated with SCI. Pain is a companion of people with SCI, as is the constant threat of pressure sores, fractures of unused limbs, venous thromboembolism, orthostatic hypotension and autodysreflexia.

With improved early intervention and medical procedures, rehabilitation today provides hope of a life expectancy approaching that of the able-bodied population. Earlier admission to specialised interdisciplinary SCI care is associated with reduced length of total hospital stay and greater and faster rehabilitation gains with fewer medical secondary complications. Much of the post-acute rehabilitation is to restore residual function of the upper limbs to enable functional independence.

Current literature indicates that regular exercise can improve physical function, reduce pain, and increase independence in community living, thus improving quality of life of people with SCI. There is also evidence that regular activity is beneficial in reducing the impact of depression and other mental states in SCI. Exercise protocols that have demonstrated benefits include Body Weight Supported Treadmill Training, Circuit Training, and Functional Electrical Stimulation (FES), either alone or in combination. Recent bio-engineering research has expanded the range of possible actions supported by FES, and includes neuroprostheses controlled from implanted stimulators. The long-term benefit of these devices is yet to be determined. Choosing appropriate physical activities is a trade-off between under-activity leading to secondary complications, or over-exertion of muscles, tendons and joints (especially the shoulder girdle) resulting in degeneration and pain. This is particularly important as the individual ages, and as obesity and other factors further load the shoulder joints.

Reported research has confirmed that the appropriate frequency, intensity, and duration of exercise varies considerably between individuals, and in the absence of universally accepted evidence-based guidelines, exercise prescription should be approached with care. Robust information on the safest and most effective forms of exercise for people with SCI is very limited. However, there is no doubt that hospital and community fitness staff and their clients would benefit from appropriate training in the specific requirements of people with SCI undertaking exercise. As in other locations, there is a need in WA for policy and practice that requires and supports ongoing education and training of fitness staff.

In the context of secondary health issues confronting people with SCI, the literature supports more active promotion of appropriate regular and sustained physical activity. This exercise needs to be relatively high to offset the issue of the smaller working muscle mass being unable to elicit an effective training load to induce structural change in the body systems.

As with the general population however, uptake and adherence to structured exercise has been shown to be difficult for people with SCI. Some of the recent research suggests the need for a focus on promotion and support of higher levels of general physical activity either in a specialized or community setting.

From a research perspective, SCI presents many challenges to the researcher. The first is the great range of individual differences between people with SCI, depending on the site of the lesion and its completeness, the age of the original trauma, health condition prior to the trauma, gender, and psycho-social factors. The second is the lack of appropriate tools with which to measure parameters of interest, such as cardiovascular and muscular fitness, or even appropriate norms to judge performance on a given task. Finally, obtaining sufficient sample sizes to conduct randomized clinical trials is not possible in a relatively small community such as Perth. With an SCI population of less than 1500 people, multi-site trials (interstate and international) are required, even though these bring their own set of challenges.

CONTENTS

1. INTRODUCTION AND PURPOSE

This report is one of four foundation documents produced as a result of the Move Again Program's (MAP's) background research. The other three documents are:

- Move Again Program: Literature Search: Part II: Barriers to Exercise for People with SCI
- Move Again Program: Information Scan
- Move Again Program: Survey Development

The purpose of these documents is to provide background information for MAP investigators and associates who collectively represent a wide range of academic and clinical backgrounds and whose experience with the SCI population is highly variable - from full time clinical involvement to virtually no direct experience.

The purpose of this search was to review key Australian and international published literature on '**Exercise and Spinal Cord Injury'**, and to present a narrative of major findings that might inform the MAP investigators and associates. While acknowledging the significance of psychosocial aspects of SCI and physical activity, the requested focus of the search was primarily on the physical domain.

Following the section on definitions and method, this document provides a context for the current evidence of benefits of exercise for people with SCI. It briefly discusses SCI and its consequences, and then summarises the major accepted physical activity benefits for the general populations and for those with SCI. Key research issues are presented, followed by evidence for the benefits of specific exercise strategies using treadmill, arm ergometer, and functional electrical stimulation activities. In addition to the references noted at the end of the document, a broader EndNote database of references, and a number of the most significant papers in pdf format, has been provided to MAP on CD.

2. DEFINITIONS AND METHOD

2.1 DEFINITIONS

The following definitions are proposed for this review:

Spinal Cord Injury

The US Centers for Disease Control (CDC) case definition is:

... a case of spinal cord injury is defined as the occurrence of an acute, traumatic lesion of neural elements in the spinal canal (spinal cord and cauda equina) resulting in temporary or permanent sensory deficit, motor deficit, or bladder/bowel dysfunction. (Thurman et al. 1995).

Individuals with SCI have lesions that affect either sensorimotor function of all four limbs (tetraplegia) or the upper limbs alone (paraplegia).

This report refers only to 'traumatic' SCI.

Tetraplegia (quadriplegia)
Impairment or loss of motor/and or sensory function in the cervical segments of the spinal cord due to damage to neural elements within the spinal canal. It results in impairments in function of the arms, trunk, legs and pelvic organs, but does not include brachial plexus or peripheral nerve damage (Maynard, Bracken et al. 1997).

Paraplegia
A term referring to impairment or loss of motor and/or sensory function in the thoracic, lumbar or sacral segments of the spinal cord, secondary to damage of neural elements within the spinal canal. With paraplegia, arm functioning is spared, but, depending on the level of injury, the trunk, legs, and pelvic organs may be involved. The term is used when referring to cauda equina and conus medullaris injuries, but not to lumbo-sacral plexus lesions or injury to peripheral nerves outside the neural canal (Maynard, Bracken et al. 1997).

Physical activity
All leisure and non-leisure body movements resulting in an increased energy output from the resting condition (Warburton, Sproule et al. 2006).

Exercise
Structured and repetitive physical activity designed to maintain or improve physical fitness (Warburton, Sproule et al. 2006).

This review refers to both the broad notion of physical activity and to structured physical exercise. The relevance and value of the former is increasingly recognized as researchers and clinicians acknowledge the significant levels of physical effort and energy consumption associated with living life in a wheelchair e.g. the energy expenditure associated with activities of daily living and with leisure time pursuits. There is little evidence that, following the acute rehabilitation stage, many people with SCI attend structured physical exercise sessions. Thus, most of the published evidence of benefits of exercise comes from specific research project and programs either during rehabilitation or in exercise facilities at specialised research centres.

2.2 METHOD

This search utilised resources including library holdings (UWA, Curtin, ECU); on-line journals; Google Scholar; and EndNote bibliographic software.

Keywords were identified during meetings with MAP investigators and from articles published in journals that are highly significant in terms of the review topic i.e. Spinal Cord, Journal of Rehabilitation Research & Development, Archives of Physical Medicine and Rehabilitation, NeuroRehabilitation, Physical Medicine and Rehabilitation Clinics of North America, Neurology, Journal of Spinal Cord Medicine, Physical Therapy, Journal of Neurologic Physical Therapy, Rehabilitation Psychology, International Journal of Rehabilitation Research, Clinical Rehabilitation, and the Journal of Neurotrauma. Specific physical activity journals scanned included Science & Sports, Journal of Applied Physiology, Palaestra, Adapted Physical Activity Quarterly, Journal of Sport & Exercise Psychology, Scandinavian Journal of Medicine & Science in Sports, European Journal of Applied Physiology These were briefly scanned for articles that addressed exercise and SCI. Resulting keywords and phrases were:

> spinal cord injur*, paraplegi*, quadriplegi*, tetraplegia*, exercis*, activit*, physical activity, rehabilitation, therapy, fitness, quality of life, pain, FES, in various strategic combinations.

The focus was on literature published in the past 10 years but included significant studies that were completed before this period.

Appropriate websites and electronic databases were consulted including Science Direct, PubMed, MedLine, ERIC, SPORTS DISCUS, PsychInfo.
Recent issues not yet available on line were reviewed in hard copy at the UWA Library and RPH library.
Prior to searching for individual papers, key review articles were identified and the bibliography and related articles scanned for further leads.
Papers were then examined firstly in terms of research ‘rigour’ e.g. with an emphasis on randomised control trials, before drawing the evidence together in a narrative format. This process was not a systematic review following strict exclusion rules, such as the Physiotherapy Evidence Database (PEDro) tool (http://www.pedro.fhs.usyd.edu.au/scale_item.html). However, many of the articles reviewed were not considered to be of adequate quality for inclusion. Others were omitted because in some cases there were many articles drawing the same conclusions. All significant reviewed articles were saved into EndNote and pdf downloads made of selected items. Many items that were reviewed but not included in the findings were exported into an Endnote database on CD for further reference by MAP and other stakeholders.

3. ABOUT SPINAL CORD INJURY

3.1 PREVALENCE

Traumatic spinal cord injuries (SCI), although uncommon, present tremendous challenges for individuals, their families and carers as well as medical staff in acute wards and long-term care facilities. The Australian Spinal Cord Injury Register (ASCIR) (Australian Institute of Health and Welfare: Cripps 2007) reported that in 2005-06 there was a total of 284 new cases of traumatic SCI, an incidence rate of 15.7 cases per million of the Australian population. Of these reported cases, over three quarters were caused by transport-related injuries (46%) and falls (33%). A smaller number were sport-related (n=35) and work-related (n=43). State and territory age-adjusted three-year annual average incident rates remained similar to rates in the 2006 report, with Western Australian rates significantly higher (22.5 per million) than the national incident rate and Victorian rates significantly lower. This is partly explained by more efficient reporting mechanisms in W.A. The number of surviving cases of SCI in Western Australia is estimated at approximately 1500 (J. Ker personal communication, March 2008).

On the ASCIR national data more than half of the cases involved injury to the cervical segments (52.5%, n=135), with 54 cases reported as being at the C4 neurological level, 31 cases were at the C5 level, and 21 at the C6 level. Together, C4, C5 and C6 cases made up 79% of cases of cervical SCI and 41% of cases at all neurological levels. The most common neurological category was incomplete tetraplegia (37%, n=94), followed by incomplete paraplegia (28%, n=73), complete paraplegia (19%, n=49) and complete tetraplegia (16%, n=41). The 15–24 year age group accounted for 25% (n=64) of the cases and the age-specific rate declined with increasing age until age group 45–54 years, then increased to age group 65–74 years and then declined thereafter.

The median duration of initial care following persisting spinal cord injury in 2005–06 was 211 days (almost 7 months), and 226 days for cases resulting in complete tetraplegia. RPH (SPC) staff report a much shorter hospital stay time than this, depending on the nature of the case.

At the current incidence rate, the projected number of SCI cases by 2021 could increase to nearly 12,000 if age-specific SCI incidence rates continued at average values evident over the period 1986-1997, and national population projections are applied (O'Connor 2005).

To put this into an international perspective, it is estimated that there are currently over 250,000 Americans surviving with SCI (National Spinal Cord Injury Statistical Centre (NSCISC(Centre)). Thus, the Australian (and Western Australian) SCI population is small by comparison, but nevertheless an important one in terms of quality of life issues faced by people with SCI in this State.

3.2 CLASSIFICATION

The generally accepted means of classification of SCI is by application of the International Standards for Classification of Spinal Cord Injury (revised 2002), written by the Neurological Standards Committee of the American Spinal Injury Association (ASIA), and endorsed by the International Spinal Cord Society (ISCoS). These guidelines are referred to as the 'ASIA Guidelines' (Association 2002), and consist of a five-category ASIA Impairment Scale (A-E), a motor score and sensory score. Twenty-eight dermatomes are assessed bilaterally using pinprick and light touch sensation for the sensory score (maximum of 112 for pinprick and 112 for light touch sensation). Ten key muscles are assessed bilaterally with manual muscle testing for the motor score (maximum of 50 for lower limbs and 50 for upper limbs). The results are used in combination with evaluation of anal sensory and motor function as a basis for the determination of the ASIA Impairment Scale. The five ASIA categories are

- ASIA A: Complete injury where no sensory or motor function is preserved in sacral segments S4-S5.
- ASIA B: Incomplete injury where sensory, but not motor, function is preserved below the neurologic level and extends through sacral segments S4-S5.
- ASIA C: Incomplete injury where motor function is preserved below the neurologic level, and most key muscles below the neurologic level have muscle grade less than 3 (active full-range movement against gravity).
- ASIA D: Incomplete injury where motor function is preserved below the neurologic level, and most key muscles below the neurologic level have muscle grade greater than or equal to 3.
- ASIA E: Normal sensory and motor functions.

Since the spinal cord is rarely completely severed, the degree of sensory, motor and autonomic sparing will differ between patients, making classification of SCI rather complicated. Such classification is extremely important for making critical acute-phase medical decisions as well as exercise prescriptions later in the post-acute rehabilitation and maintenance phases. The classification is a combination of region, spinal nerves affected, and degree of neurological completeness. Spinal cord syndromes are also included. Adopting an internationally accepted classification system is an important step in establishing SCI research protocols. A distinction between upper motor neuron (UMN) and lower motor (LMN) neuron dysfunction is very important, from a research and a clinical perspective. Upper motor neurons are motor neurons that originate in motor region of the cerebral cortex or the brain stem and carry motor information down the spinal cord and are not directly responsible for stimulating the target muscle. Lower motor neurons originate in the brain stem or anterior horn of the spinal cord and terminate at the muscle fibre i.e. they bridge upper motor neurons to target muscles. Upper motor neuron dysfunction involves damage to descending motor tracts which results in spasm since spinal reflex circuits are preserved, but also increases the chances of re-activating spinal stepping circuits in exercise routines. Lower motor neuron damage usually occurs with lesions at or below T10, and results in denervation of the sensori-motor function and gives rise to flaccid paralysis and areflexia. Such patients are less amenable to direct electrical stimulation (FES prostheses) for exercise protocols.

In Paralympic sports, classification is a way of grouping athletes with similar function or ability for the purpose of competition. Functional classification exists to try and create “fair” competition among athletes with different disabilities. Over the years classification has evolved from being a pure medical test, to including observation of the athlete performing the sport. There are currently eight classes in SCI, from T51-T58. Classes T51 – T54 are for athletes in a wheelchair who are competing in track events, and classes T55 – T58 are for athletes who are competing in field events. An athlete who is classed as T54 is completely functional from the waist up. An athlete who is classed as T53 has restricted movement in their abdominals. An athlete who is classed as either T52 or T51 has restricted movement in their upper limbs.

Certain sports rate players individually, regardless of diagnosis. For example, wheelchair basketball has a unique system; the 8 different classifications are based on sport-specific tests of shooting, passing, rebounding, pushing, and dribbling abilities, rather than a medical diagnosis or muscle function examination. Higher classification numbers represent greater basketball skills. Athletes are given a numeric point value based on their classification status; the maximum allowable number of points on the floor is 14.0. Currently, the Western Australian Wheelchair Basketball team (Perth Wheelcats) is one of the best in the world, due partly to two amputee players and several high point SCI players.

3.3 TREATMENT AND REHABILITATION

The current medical treatment is based on a teamwork approach to the early stabilisation of the spine (usually with spinal orthoses) and decompression of the spinal canal, minimising of inflammatory and apoptotic reactions, sound patient management i.e. reduction of risks due to complications and infection, better hygiene and patient handling, and early mobility training, including passive and active exercise (Branco, Cardenas et al. 2007). There are also some promising new therapies still in the experimental stage. These include molecular and cell-based therapies (Kakulas 2004; Ramer, Ramer et al. 2005; Bradbury and McMahon 2006; Belegu, Oudega et al. 2007), although the hurdles for translation are significant (Dobkin 2007). Nevertheless, some cell and one molecular-based therapies are beginning to reach phase 1 clinical trial (http://clinicaltrials.gov/search/term=Spinal+Cord+Injury; http://www.portailderecherche.ch/unizh/p9471.htm). Neuroprostheses are also under development (Giszter 2008).

Rehabilitation has been defined by the World Health Organization as a process aimed at enabling people with disabilities to reach and maintain their optimal physical, sensory, intellectual, psychological and social functional levels. Rehabilitation provides disabled people with the tools they need to attain independence and self-determination.
(WHO http://www.who.int/topics/rehabilitation/en/)

"Rehabilitation is therefore a progressive, dynamic, goal-oriented and often time-limited process, which enables an individual with an impairment to identify and reach his/her optimal mental, physical, cognitive and social functional level. Enhancing quality of life is regarded as an inherent goal of rehabilitation services and programs given their focus on interventions to minimize the impact of pain and physical and cognitive impairment, and on enhancing participation in work and everyday activities. SCI rehabilitation involves a multitude of services and health professionals and is initiated in the acute phase and continues with extensive and specialized inpatient services during the sub-acute phase. Inpatient rehabilitation is an important stepping stone towards regaining and learning new skills for independent living. Here patients engage in an intensive full day program with services which may include nursing, physical therapy, occupational therapy, respiratory management, medical management, recreation and leisure, psychology, vocational counselling, driver training, nutritional services, speech pathology, social worker, sexual health counselling, assistive device prescription and pharmaceutical services. Rehabilitation continues with planning for discharge back to the community and finally, re-integration into former or new roles and activities within the community. Family and peers have important roles throughout the rehabilitation process" (Eng and Miller 2006).

In a study of rehabilitation of SCI in the United States over the last 30 years, (De Vivo 2007) reported that

- acute care and rehabilitation lengths of stay declined dramatically over time,
- mean functional independence measure motor score at discharge and gain during rehabilitation decreased, whereas gain per day increased (probably indicating early discharge)
- the probability of neurologic improvement from admission to discharge increased
- the odds of medical complications decreased during in-patient treatment, but increased post-discharge
- re-hospitalisations declined over time
- community integration improved over time, and
- first year mortality rates improved, but longer term mortality rates showed no improvement since 1982.

Other authors point to a 2000% increase in post-SCI life expectancy over the last 50 years compared to a 30% increase in life expectancy of the able bodied population (De Vivo, Kartus et al. 1989). Similar findings were reported by (Franceschini, Clemente et al. 2003), who found Quality of Life following SCI was highly correlated with ability to drive and work, both indices of independence.

These data indicate that steady improvements have occurred for many treatment outcomes. However, there remains a need for more effective methods of SCI prevention, treatment, and rehabilitation to target those outcomes that have not improved and remain suboptimal. It also highlights the fact that SCI must be viewed as a dynamic condition in which an individual's functional limitations, needs, physical abilities and social circumstances are constantly changing.

4. THE IMPACT OF SCI

4.1 COMMON CONSEQUENCES

Each SCI patient presents with unique physical, emotional and social circumstances which will determine the success or otherwise of rehabilitation efforts. They face particular health challenges throughout their lives.

The physical consequences of SCI and consequent deficits in volitional control and sensation, as well as autonomic functions, will depend on the level of the lesion, the completeness of the injury, the relative robustness of the patient, and the standard of medical care immediately following the trauma.

The higher the level and the completeness of the lesion, the greater the impact on body function (Ragnarsson, Stein et al. 2004). For example, in cervical and upper thoracic level SCI, respiratory complications are one of the leading causes of morbidity and mortality (De Vivo, Black et al. 1993; De Vivo, Krause et al. 1999; Sheel, Reid et al. 2006). This is not only due to the loss of the respiratory pump, itself a major problem to be dealt with via mechanical ventilation. Over time, lung compliance diminishes, reducing inspiratory capacity and expiratory reserve volume (Baydur, Adkins et al. 2001). The loss of abdominal muscle control also affects cough and clear respiratory secretions, speech, and postural control.

A low level of physical capacity may be associated with a decrease in activity (Janssen, Dallmeijer et al. 2002); (Dallmeijer, van der Woude et al. 1999); (Muraki, Tsunawake et al. 2000), functional status (Noreau, Shephard et al. 1993; Dallmeijer and van der Woude 2001); and participation (Noreau and Shephard 1992). A vicious cycle of decreased capacity leading to decreased activity, which in turn leads to further decreases in physical capacity, may often be the result (Haisma, van der Woude et al. 2006).

Pain is a significant issue in SCI, especially in the acute phase of treatment. It is more persistent in tetraplegia than paraplegia (van Drongelen, de Groot et al. 2006), but decreases over time, and is inversely related to functional outcomes of rehabilitation, especially development of shoulder strength. Arm and shoulder pain is common in wheelchair users and may be exacerbated or improved by exercise. However, in general, exercise has been shown to be successful in controlling pain associated with SCI (Ditor, Latimer et al. 2003; Martin Ginis, Latimer et al. 2003; Donnelly and Eng 2005; Drongelen, Groot et al. 2006; Nawoczenski, Ritter-Soronen et al. 2006; Dyson-Hudson, Sisto et al. 2007; Nash, van de Ven et al. 2007).

The impact of SCI has many psychological and social sequelae, for SCI individuals, their families and carers, as well as for the broader community. The quality of life (QOL) of individuals with SCI is reported to be lower than for the general population (Hammell 2004; Hammell 2007). It is often reduced because of pain, lack of access to the built and social environments, financial burdens, reliance on support, and mental states including depression. Although difficult to define, it has been reported that several areas of QOL are of particular significance to people with SCI eg health status, psychological support, control and independence, and the ability to engage in productive activities eg;(Hammell 2007);(Boschen, Tonack et al. 2003).

Major improvements in the early treatment of SCI have resulted in an increased life expectancy for patients (Tyroch, Kaups et al. 1997). Although there will be unique differences in the degree and extent of sequelae, there are aspects common to all SCI. These include neuromuscular weakness and spasm, bone loss, over-use injuries, cardiovascular and respiratory complications, loss of autogenic control (bladder, sexual function, thermoregulation), changed lipid metabolism, and pain and depression. From a body system perspective, there is further evidence of specific SCI-related deficiencies.

4.2 IMPACT ON SPECIFIC SYSTEMS

4.2.1 Neuromuscular

The most obvious outcome of SCI is loss of sensory and motor function below the level of the lesion. This can result in

- spasm in the affected limbs,
- general muscle deconditioning,
- bone demineralisation including lower limb osteoporosis and greater risk of fractures from falls and minor injuries,
- over-use injuries in shoulder girdle muscles and joints, especially rotator cuff tendonitis, frank tears, general impingement syndrome, carpal tunnel syndrome, wrist tendonitis, and elbow pain,
- muscle imbalances due to overly strong anterior chest and arm muscles overpowering weak posterior scapular and cervical stabilisers,
- periods of immobilisation can lead to decubiti (‘lying down’) ulcers, or pressure sores.

Ageing with SCI results in an increase in shoulder pain and a decline in muscle strength independent of the ageing process (Adkins 2004).

4.2.2 Cardiovascular

For people with SCI, the direct traumatic changes to the cardio-vascular (C-V) system, as well as complications attributable to long-term inactivity, present distinct risk factors for cardiovascular disease (CVD) CVD (Bauman, Kahn et al. 1999; Bravo, Guizar-Sahagun et al. 2004). Epidemiological studies have shown that C-V disease is the most frequent cause of death among people surviving >30 years with paraplegia (Whiteneck 1992; Bauman, Kahn et al. 1999; Lavis, Scelza et al. 2007), and respiratory complications the leading cause of death in tetraplegia (Capoor and Stein 2005). The decline in C-V function in SCI is similar to that in the able-bodied population, but at an accelerated rate (Bauman, Spungen et al. 1999). Much of this increased risk is due to prolonged bed rest following SCI (Haisma, Bussmann et al. 2007).

SCI leads to various abnormalities in the regulation of cardiac and circulatory function. In SCI above T1, hypotension results, with mean arterial pressures of 70mm Hg common (King, Lichtman et al. 1994). In addition, the heart undergoes structural changes because of the altered circulatory dynamics, largely the effect of changed systemic volumes and pressures. Left ventricular atrophy is a common result in tetraplegia (Kessler, Pina et al. 1986). In paraplegia, increases in cardiac output are accommodated by increased resting heart rate (HR) because stroke volume (SV) is lower due to decreased venous return from immobile lower extremities or venous insufficiency in paralysed limbs (Jacobs and Nash 2004). Aging persons and those with higher levels of severity of SCI are at greater risk of CVD (Groah, Weitzenkamp et al. 2001). Patients are also vulnerable to a condition known as autonomic dysreflexia (sudden high blood pressure).

Changes in the peripheral vascular system in SCI also contribute to the risk of CVD in SCI. The volume and velocity of lower limb arterial circulation is diminished by up to two-thirds after SCI (Taylor, Ewins et al. 1993), increasing the risk of thrombosis. In particular deterioration in the endothelium leads to premature artherosclerosis (Anderson 2003).

People with SCI have higher incidence of serious medical complications and an increased risk of coronary heart disease associated with factors including

- Abnormal lipoprotein profiles (Bauman and Spungen 2000; Bauman and Spungen 2001),
- Lower HDL and elevated LDL cholesterol (Manns, McCubbin et al. 2005)
- Elevated body fat (Spungen, Adkins et al. 2003; Manns, McCubbin et al. 2005),
- Abnormal glucose metabolism (Bauman and Spungen 2001)
- Peripheral vascular dysfunction (de Groot, Hjeltnes et al. 2003; Wecht, De Meersman et al. 2003),
- Risk of DVT (Miranda and Hassouna 2000)
- Abnormal haemostatic function (Frost, Roach et al. 2005),
- Depressed hormone levels (Bauman and Spungen 2000),
- Reduced aerobic fitness (Manns, McCubbin et al. 2005)

Obesity is a particular health risk for people with SCI ((Bauman and Spungen 2001; Nash and Gater Jr 2007). Moreover, the associated risks are increased dramatically when associated with other risk factors such as vascular inflammation, dyslypidemia, insulin resistance, and hypertension. This collective has been labelled the 'metabolic syndrome' (Gater Jr 2007). For people with SCI, obesity is also associated with an increased risk of osteoarthritis, particularly for those who are able to use upper extremities for mobility and transfers. Osteoarthritis, carpel tunnel syndrome, rotator cuff dysfunction and ulnar neuropathies are particular risks which are exacerbated by obesity (Ballinger, Rintala et al. 2000). As upper-extremity pain and dysfunction occur, activity patterns typically decrease, leading to reduced physical activity and weight gain. Prescription of physical exercise thus requires a careful balance between under-use and over-use of vulnerable joints.

While there is an abundance of published evidence to show exercise reduces C-V risk factors in the able-bodied population (Warburton, Nicol et al. 2006), quality evidence on this topic is quite sparse for the SCI population(Warburton, Eng et al. 2007). Logically, aerobic fitness is a good predictor of C-V risk, but it is difficult to measure in a meaningful way in SCI exercise. Because of the reduced muscle mass in SCI, Resting Metabolic Rate (RMR) is 14-17% lower when compared to age-matched control subjects (Buchholz and Pencharz 2004). It is relatively easy to measure direct oxygen consumption during exercise in SCI populations, but lacking population norms against which to judge such observations makes individual evaluation difficult. Recent attempts to develop protocols to indirectly measure VO2 (Vidal, Medina et al. 2006) are encouraging. To measure oxygen consumption, an individual needs to be undertaking a volitional task which utilises the largest muscle mass possible in a standard skilled task, such as running, walking, cycling, stair-climbing etc. In SCI subjects, the amount of working muscle available for work is greatly diminished, even in subjects with incomplete lesions. Following SCI, it has yet to be determined whether the remnant working muscle mass can challenge the C-V system adequately to provoke adaptation.

4.2.3 Respiratory

The respiratory system is a complex one involving structural and neural elements that work automatically together to control inspiration and expiration in response to metabolic demands of the body. In SCI, the smaller working muscle mass means that the lungs and airways are not subject to sufficient stress to warrant adaptation. However, the neural control of respiratory (intercostal, diaphragm and abdominal) muscles does respond to training. For example (Silva, Neder et al. 1998), showed that following three 30 minute sessions of arm cranking aerobic training per week for a total of six weeks, SCI subjects demonstrated a significant increase in forced vital capacity (FVC) and ventilatory muscle endurance when compared with matched able-bodied controls. Similar results have been reported elsewhere (Le Foll-de-Moro, Tordi et al. 2005; Sutbeyaz, Koseoglu et al. 2005). However, evidence indicates that the training loads following SCI need to be relatively high, 70-80 percent of maximum heart rate, three times per week for a minimum of six weeks (Sheel, Reid et al. 2006).

Often used to improve breathing mechanics and reduce dyspnea in cervical SCI, Inspiratory Muscle Training (IMT) is not supported by current evidence, and may be counter-productive if used too vigorously (Brooks, O'Brien et al. 2005).

Other mechanical aids which might improve breathing mechanics in cervical SCI include abdominal binding, which reduces the respiratory effort (Hart, Laffont et al. 2005), chest wall vibration (Ribot-Ciscar, Butler et al. 2003); (Butler, Godfrey et al. 2006), and immersion in shoulder-deep water (Thomaz, Beraldo et al. 2005).

Obstructive sleep apnea is very common in SCI, making lifestyle education such as reducing alcohol intake, increasing physical activity, and combating obesity such important targets for interventions (Biering-Sorensen and Biering-Sorensen 2001).

4.2.4 Autonomic

The autonomic sympathetic system nerves descend in the spinal cord and exit with motor nerves at the thoracolumbar segments. As no sympathetic nerves exit in the cervical segment, individuals with cervical SCI exhibit decentralisation of the sympathetic nervous system. This leads to the following complications in SCI, depending on the level of the lesion:

- Loss of autonomic control over adrenal glands,
- Loss of genito-urinary control, resulting in bladder and bowel function and erectile dysfunction in males,
- risk of urinary tract infections,
- cardiac and circulatory dysfunction described earlier- including immunodysfunction, clotting disorders, altered insulin metabolism, orthostatic incompetence,
- thermal dysregulation at rest and during exercise.

In summary, SCI leads to deterioration in body systems, the extent of which depends on many physical, psychological and social factors. SCI presents as a complex issue and any intervention must take a multitude of factors into account (Biering-Sorensen 2005).

5. PHYSICAL ACTIVITY FOR ALL

5.1 PHYSICAL ACTIVITY/EXERCISE AND THE GENERAL POPULATION

It is now universally accepted that physical activity can improve both quality of life and health status. Suitable regular daily physical activity is a major factor in preventing chronic diseases and can provide a wide range of physical, social and mental health benefits (WHO 2006(a)). Conversely, physical inactivity increases all causes of mortality, doubles the risk of cardiovascular disease, Type 2 diabetes, and obesity. It also increases the risks of colon and breast cancer, high blood pressure, lipid disorders, osteoporosis, depression and anxiety (WHO 2006 b)). The 2003 Australian Burden of Disease Study indicates that physical inactivity was the fourth leading cause of burden of disease in Australia. It was estimated that physical inactivity was responsible for approximately 7% of the total burden of disease and injury for all Australians (6% of total for males and 7% of total for females) (Begg, Vos et al. 2007).

An increase in the level of physical activity and the associated improvements in the health of the community will also provide significant benefits to the economy by decreasing the burden on the health care system. The direct annual health care cost attributable to inactivity is estimated to be around $377 million per year (Stephenson, Bauman et al. 2000). These authors also calculated that 122 deaths per year from coronary heart disease, non-insulin dependent diabetes and colon cancer could be avoided for every 1% increase in the proportion of Australians who achieved the recommended level of physical activity. It is now well established that disease prevention is only one aspect of health and that being physically active has a wide range of mental and social health benefits.

Co-ordinated health promotion campaigns are now commonplace in many developed countries, including the United States, Great Britain, Australia, Canada, and New Zealand. These Australian campaigns typically target low physical activity levels and poor dietary patterns. The current national physical activity initiative was backed by a series of preparatory papers (Egger, Donovan et al. 1999) that reviewed the research literature concerning health benefits of regular physical activity, examined health intervention strategies to increase activity in the population, and set activity benchmarks for the Australian population. These papers reviewed a wide range of studies of different occupational, gender and cultural groups and clearly demonstrated a decreased risk of premature mortality and morbidity with both increased occupational and leisure time physical activity. From all of these reviews, it is now recognised that physical inactivity is an independent risk factor for a range of diseases, and that physical activity is important in the maintenance of optimal health.

In Western Australia, the promotion of physical activity as a health intervention is coordinated by the Premier's Physical Activity Taskforce (http://www.beactive.wa.gov.au/). The Taskforce links government and community agencies to strengthen the promotion and development of physical activity programs for healthy lifestyles, for the environment and to build stronger communities.

The Taskforce website (Taskforce) offers information for Western Australians on how to be active, as well as provides information for government and community agencies on how to promote and support physical activity. It has been supported by a series of benchmarking research initiatives to gauge the level of activity of West Australians. The latest report (Milligan, McCormack et al. 2007) shows that a total of 59% of Western Australian adults reported participating in sufficient physical activity of 150 minutes of moderate-intensity physical activity on five or more days per week. This was an increase of 4% compared to 2002, with walking the most reported activity, whether for recreation or work/transport-related. While there was little evidence about physical activity levels of people with disabilities the report recommended using specific physical activity strategies to target population subgroups with particularly high levels of physical inactivity and low levels of sufficient physical activity (i.e. older adults, under resourced groups, and those overweight and obese).

5.2 PHYSICAL ACTIVITY AND SCI

Since the mid twentieth century, it has been increasingly accepted that physical activity can improve both quality of life and health status in the SCI population. The pioneering exercise therapy modality for SCI was developed during WWII by Sir Ludwig Guttman at Stoke Mandeville Hospital UK, one of the largest hospitals in Europe with the largest spinal injuries department in the world. Since then, physical activity has been actively promoted internationally to address the physical, psychological and social needs of people with SCI. Therapy followed by participation in competitive sport by people with SCI was soon exhibited extended in the 'friendly games' against a Dutch team in 1948 and subsequently blossomed into the Paralympic movement. Today many thousands of competitors compete every four years in parallel with, and in some events integrated with, the able-bodied competition. In WA, this work was adopted and championed by Sir George Bedbrook and John Johnston at Royal Perth Hospital, Shenton Park, who together developed a disciplined physical approach to therapy (Lockwood and Lockwood 2007).

As evident in the Paralympics, **many people with SCI can achieve significant physical reconditioning** e.g. those with upper limb function can participate in a wide range of 'normal' or adapted activities and sports, or can walk with assistance from orthoses, mechanical or electrical. Many can pedal ergometers with or without assistance, lift free weights, use hand cycles, paddle kayaks, sail yachts, swim, or wheel chairs on circuits or track and road races.

These activities and achievements are however, confined to a relatively small sector of the SCI population and international research clearly indicates that **the majority of people with SCI have low levels of physical activity** (Dearwater, LaPorte et al. 1986; Washburn and Figoni 1998; Bernard, Mercier et al. 2000)**.** While no reliable data was located on participation or fitness levels of people with SCI in Australia, anecdotal evidence suggests significantly lower levels of physical activity than in the general population. In an attempt to measure the physical activity levels of children and adolescents with a range of physical and mental disabilities, one WA study has reported lower levels of engagement (Packer, Briffa et al. 2006). Similar results had previously been reported for 'people with disabilities' on a national level (Lockwood and Lockwood 1993).

Australian research on the health benefits of physical activity for people with SCI is very limited, and has generally focused on particular aspects of exercise such as thermoregulation (Gass and Gass 2001; Gass, Gass et al. 2002) or specific physiological responses to specific exercise (Lassau-Wray and Ward 2000). There is currently **no definitive research on the specific dose/effect relationship for exercise and SCI** but the standard of research in the area is gradually improving and there are **increasing reports of more general positive physical activity outcomes**. International research on the benefits of physical activity, together with a heightened focus on equity issues and various other economic and political considerations, have lead to **recommendations for increased activity by people with SCI** – both internationally and in

Australia. This recommendation is based on premises including; physical activity has health benefits for all; it can assist in reducing the secondary health issues associated with SCI, and; specific exercise can assist in recovery of spinal cord function (see Section 6).

Physical activity has health benefits for all – including those with disability. In addition to activity benefits reported from research in the general population, studies of people with disabilities report a **wide range of positive physical activity outcomes** (Rimmer, Riley et al. 2004). These include improved cardio-vascular and respiratory function, and musculo-skeletal function (Nash, van de Ven et al. 2007), and reduced risk from cardio-vascular disease and type II diabetes (Kocina 1997; De Vivo, Krause et al. 1999), obesity, reduced muscle bulk and tone with subsequent muscle weakness, muscle spasm, bone loss (osteoporosis), reduced joint mobility, and predisposition to falls. These outcomes are general ones that have direct implications for people with SCI.

The **psychological benefits** derived from regular exercise include greater self-control, goal setting, cathartic expression of self; reduced risk of mental states arising from poor self-esteem and self-worth leading to depression and other psychiatric conditions; higher satisfaction with life (Tasiemski, Kennedy et al. 2005), improved quality of life (Kennedy and Rogers 2000; Kreuter, Siˆsteen et al. 2005; Kennedy, Lude et al. 2006; Hammell 2007).

However, it is further noted that all of these benefits are reduced when physical impairments lead to lower levels of physical activity (Taylor, Baranowski et al. 1998).

With the increased life expectancy of people with SCI today (e.g. (Tyroch, Kaups et al. 1997), there is also increased opportunity to develop the same chronic conditions as seen in the general population. It is now known that exercise can play a significant role in **modifying the risks** associated with many of these conditions. Cardio-vascular disease for example, is the leading cause of death in the general population and in people with SCI (De Vivo, Black et al. 1993; Bravo, Guizar-Sahagun et al. 2004). Moreover, since age-related changes occur at earlier ages in people with SCI (Capoor and Stein 2005), there are further risks and challenges to maintain health, function, and quality of life.

Exercise can assist in **reducing secondary complications of SCI** including pressure sores, urinary tract infections, hyperextension, pain and depression (Johnson, Gerhart et al. 1998).

Despite their lower rates of participation in physical activity people with disabilities have not been significant targets of Australian **physical activity and health promotion** campaigns. It has been suggested that this may be partly due a biomedical conceptualisation of health and disease in which people with disabilities are classified as already 'ill', and therefore beyond the reach of health promotion initiatives aimed at the 'middle-ground' of the population. This is further complicated by the **lack of evidence-based activity guidelines for the SCI population**. While the "Be Active" campaign is based on clearly stated population activity norms, for some individuals with SCI, these might be contra-indicated or lead to over-use syndromes. It is now over ten years since the paucity of research into exercise and SCI was raised internationally (Rimmer, Braddock et al. 1996). Most of the studies since that time have investigated novel exercise therapies, such as functional electrical stimulation (FES) and body-weight-supported treadmill training (BWSSTT). While more recent work is now investigating application of behavioural models to exercise uptake and adherence (eg see reports and references in Literature Review Part II: Barriers to Exercise for People with Spinal Cord Injury), there is little published that provides a guideline to broader health promotion amongst people with SCI.

6. RESEARCH INTO SCI AND EXERCISE

6.1 RESEARCH ISSUES

The development of valid and reliable tools to measure activity levels or fitness of people with SCI (Heath and Fentem 1997), and norms against which to compare an individual result, remains elusive both in Australia and internationally.

The development of **research protocols** and an evidence base on which to prescribe exercise for SCI populations has been hampered by the lack of **randomised controlled trials** (RCT) and other robust research. Very few studies have utilised RCT protocols and the majority are best described as quasi-experimental in nature, and thus less scientifically rigorous. There are ready explanations for this observation. In RCT protocols, a homogeneous base sample is the key with random assignment to treatment/control groups ensuring that groups are equivalent in the underlying variables of interest. Because the SCI population is relatively small, ensuring homogeneity in key variables becomes problematic. Research and interpretation of results from studies of people with SCI is challenged by the variability of SCI itself (Dobkin, Apple et al. 2003). Finding matched samples (e.g.on lesion level and completeness, age, gender, pre-trauma fitness and motivation levels, degree of training, etc) presents a serious problem to researchers adopting traditional RCT methodologies. Often the effect size required (e.g. training effect) is not matched to a sufficiently large sample and thus experimental power (confidence) is low. However, as therapists have often noted, small changes in function are, in reality, often major milestones in treatment regimes, progress toward independent living, and improving quality of life. Collaborative research across centres may be one way of building potential pools of subjects for RCT (Fawcett, Curt et al. 2007; Lammertse, Tuszynski et al. 2007; Steeves, Lammertse et al. 2007; Tuszynski, Steeves et al. 2007). However, this does not guarantee success, as illustrated by Dobkin and co-researchers (Dobkin, Apple et al. 2003) who were unable to recruit sufficient subject numbers from five cooperating spinal centres in Canada over a 2.25 year trial period.

RCT studies also require rigorous criterion measures with demonstrated validity, reliability and objectivity. This is particularly so for more subjective variables such as Quality of Life, depression scales etc. Other outcome variables such as maximum oxygen consumption, work capacity and respiratory data have different end-points for different SCI lesion types, so pooling data across subjects is invalid without some form of normalisation process. A recent international symposium (Anderson, Beattie et al. 2005), has suggested criteria for research in SCI.

Other research considerations include the ethical issue of **assigning** SCI patients to 'control group' status when exercise is thought to be inherently beneficial, the problems of **retention and compliance** in experimental and control groups to ensure sufficiently long exposure to the 'treatment' to produce an effect. It requires considerable 'motivation' for people with SCI to attend exercise (or control activity) sessions on a regular basis, because they often have to contend with secondary medical/health issues, as well as transport and support demands.

Some researchers have taken advantage of the strengths of **qualitative, case-based research** (McBurney, Taylor et al. 2003). In this approach, gains from a treatment are examined in detail across a number of cases, and conclusions can be drawn from the frequency of positive gains using non-parametric statistical techniques or emerging themes in exploratory work. This approach is receiving increased attention in broad areas of clinical research where large numbers of sub-types are difficult to find (Rutledge and Loh 2004). Such fundamental research would contribute to the development of appropriate activity standards for people with SCI.

Several **physical activity scales** for people with disabilities have been developed in recent years. The Physical Activity Scale for Individuals with Physical Disabilities (Washburn, Zhu et al. 2002) is one such tool which is a questionnaire-based measure of the number of days a week and hours daily (categories) of participation in recreational, household, and occupational activities over the past seven days. It was shown to have reasonable internal consistency and utility. Another such scale has been developed by Rimmer and colleagues (Rimmer, Riley et al. 2004). A particularly promising recent approach is the work of the McMaster group (Martin Ginis, Latimer et al. 2005), in developing an interview-based activity scale for Canadians with disabilities, including those with SCI. This scale reflects the difficulty in measuring intensity of activity (Shephard 2003). The Physical Activity Recall Assessment for People with Spinal Cord Injury (PARA-SCI), was developed to measure the type, frequency, intensity, and duration of three types of physical activity undertaken by people with SCI; leisure time physical activity, activities of daily living, and cumulative activity (Martin Ginis, Latimer et al. 2005). It is based on a semi-structured interview protocol with a physical activity intensity classification system suitable for people with SCI. The intensity scale was validated on a sub-set of SCI subjects (C5 or lower) who undertook a progressive exercise test and a 1RM maximum load they could lift, and subjects then estimating the level of exertion using the Borg Rating of Perceived Exertion. These data were then compared to ratings on physical activity using PARA-SCI. Overall, the tool showed moderate reliability and partial validity, although the authors did express some concerns about the sample used, and the responses of this population, given the likelihood of intervening complications (pain, motivation, etc).

There are no well-developed **physical activity norms for the SCI population** (Janssen, Dallmeijer et al. 2002). As more is learned about physical exercise and SCI, there is increasing comment on the lack of validity and possible risks of applying able-bodied physical activity norms to this group. For example, the SCI related impairment might reduce the capacity being measured, and there is no consideration of associated ceiling effects whereby a person with SCI may be operating near their full physical capacity.

The next section will examine the efficacy of three well-established exercise protocols in SCI rehabilitation.

6.2 SCI RESEARCH

Research protocols investigating benefits/adaptations to exercise in people with SCI have traditionally utilised one of three strategies; treadmill training with partial body weight support, arm ergometer exercise/circuit/weight training, and training utilising functional electrical stimulation (FES).

6.2.1 Treadmill Training With Support

Traditional therapy for incomplete SCI was supported over-ground walking, either with bars or frames. The therapy is still utilised today. More recently, therapists have utilised partial body-weight supported treadmill training (BWSTT), in which the body weight is partially supported (by bars and/or assistants), and the lower limbs are moved volitionally or with assistance over the treadmill bed (Dobkin, Apple et al. 2003; Barbeau, Basso et al. 2006; Dobkin, Apple et al. 2006). The rationale for such step training is the belief that intact spinal circuits responsible for much of the basic movement patterns may be preserved with repetition (Edgerton, Tillakaratne et al. 2004; Barbeau, Basso et al. 2006; Edgerton, Kim et al. 2006; Edgerton, Courtine et al. 2008), and that the exercise might of itself induce a training effect. There is very limited evidence to support this assertion. For example (Ditor, MacDonald et al. 2005) studied the effects of a four month intervention utilising BWSTT on six SCI subjects (ASIA A and B, C4-T12) who attended 15 min/day (3x5min bouts) three days per week for four months. Criterion measures included femoral (exercising; muscular), carotid (elastic) and brachial (non-exercising control; muscular) artery dimension and function before and after training, and continuous heart rate and blood pressure were monitored. The results demonstrated no exercise-induced change in femoral or carotid artery cross-sectional area, blood flow or resistance and no change in carotid artery compliance following the 4 months of BWSTT compared to the non-exercising control brachial artery. However, there was a significant exercise-induced increase in femoral artery compliance. There were no exercise-induced changes in HRV or BPV when all participants were considered together. In another study of incomplete quadriplegics, the authors (Ditor, Kamath et al. 2005) reported that there were significant reductions in some autonomic functions without worsening orthostatic intolerance.

In a major study of BWSTT compared with conventional over-ground therapy (Dobkin, Apple et al. 2006) recruited a total of 146 subjects from six regional centres within 8 weeks of SCI for a single-blinded, multi-centre, randomized clinical trial (MRCT). Subjects were graded as ASIA B, C, or D with levels from C5 to L3 and had a Functional Independence Measure for locomotion (FIM-L) score <4. They received 12 weeks of equal time of BWSTT or a control therapy. Specifically, the Spinal Cord Injury Locomotion Trial (SCILT) found that BWSTT was equally effective when compared with control overground training therapy in the first 4 months after incomplete SCI. Primary outcomes were FIM-L for ASIA B and C subjects and walking speed for ASIA C and D subjects 6 months after SCI. Importantly, the BWSTT and control therapy involved equal intensities of intervention of 1 hour a day for 12 weeks (BWSTT: stretching 10mins, 20-30 mins BWSTT, overground walking 10-20 mins when feasible; Control: standing, stepping [time spent stepping depended on subject's ability and fatigue]; stretching 10 mins, overground walking 30-45 mins with facilitation and assistive devices). The study demonstrates the success of intensive standing and walking rehabilitation soon after injury and can serve as a control for future comparison of new approaches and other treatment regimens.,Another outcome for this study was the use of a multi-centre approach in investigation to increase the available subject pool. Further analysis (Dobkin, Barbeau et al. 2007) suggested that most of the gains were achieved in the first 12 weeks of therapy. The study has generated considerable debate (see Editorials and correspondence in Neurology, 2006, vol 67 November pp 1900-1902)

Another study, (Hicks, Adams et al. 2005) investigated the long-term effects of BWSTT on functional walking ability and perceived quality of life in persons with chronic incomplete spinal cord injury (SCI), and whether any observed training adaptations were maintained following cessation of the BWSTT program. Fourteen subjects participated in a 3-session per week program for 12 months, with a relatively high (80%) adherence rate). All subjects improved in treadmill walking ability (54% reduction in required external body-weight support (BWS), 180% increase in treadmill walking speed, 335% increase in distance walked/session), and six subjects improved their capacity to walk over ground. There were accompanying increases in satisfaction with life and satisfaction with physical function, both of which were significantly correlated with improvements in treadmill walking ability. All but one subject returned for follow-up assessment 8 months post-training; while there was a slight decline in treadmill walking performance, over ground walking scores remained relatively stable. The only change in subjective well-being in the follow-up was a slight decrease in satisfaction with physical function. (Wernig 2006a) commented on the need to carefully describe the degree of paralysis of patients, described by manual muscle testing, as well as a full description of the 'rules of training' and some measure of the amount of therapy assistance provided to each patient.

It is possible that a combination of BWSTT and electrical stimulation might improve inter-limb coordination (Field-Fote and Tepavac 2002), although the evidence of this study was not strong.

Other authors (Martin Ginis and Latimer 2007) noted changes in feeling states and pain perception during single bouts of BWSTT.

In summary, BWSTT is not without major debate in the literature (Barbeau, Basso et al. 2006; Wernig 2006b). The main argument concerns the definition of each therapy type, use of control groups (BWSTT Vs conventional supported walking Vs no activity) and treadmill speed adopted in BWSTT. It seems that some conventions need to be adopted before different therapies can be effectively compared. That is BWSTT and conventional supported walking both work but a superiority of one over the other has yet to be convincingly demonstrated. Further evidence (Abel, Schablowski et al. 2002), suggests gait analysis can also be an effective tool in measuring change of skill levels in BWSTT. A recent systematic review of the various strategies for gait rehabilitation (Lam, Eng et al. 2007) concluded that early interventions were best, and that a combination of strategies should be undertaken to get the best patient outcomes.

6.2.2 Arm ergometer exercise/circuit/weight training

Physiological responses to SCI show diminished capacity for work and reduced system responses (Schneider, Sedlock et al. 1999), due to the loss of muscle mass available to act as trunk stabilisers and prime movers, the arms having to provide both functions. This, coupled with reduced metabolic drive (adrenergic and nor-adrenergic dysfunction) and cardiac and circulatory control mechanisms, reduces the available resources available to meet the demands of tasks. Exaggerated heart rate responses to exercise have previously been noted, as has the observation that SCI requires higher levels of oxygen consumption to perform the same work intensity as able-bodied subjects (Hoffman 1986; Davis and Shephard 1988).

Since SCI affects the lower limbs, but spares all or some function in upper limbs, it is most likely that residual function in the upper limbs can be improved by regular arm exercise using arm ergometers, weights and circuit exercises, or other arm activities such as hand cycling, swimming or wheelchair pushing. In a study of the safety and effects of circuit resistance training (CRT) on peak upper extremity cardiorespiratory endurance and muscle strength in paraplegic men, Jacobs and colleagues (Jacobs, Nash et al. 2001) subjected 12 complete T5-L1 SCI men to 12 weeks of CRT using isoinertial resistance training, and found no evidence of injury, but significant improvement in peak oxygen consumption, time to fatigue, and peak power output. In a separate study the authors (Nash, Jacobs et al. 2001) also demonstrated a drop of TC/HDL-C from 5.0 to 3.5 following three months of CRT. The benefits of CRT has been found in many other studies (Davis, Plyley et al. 1991; Durn, Lugo et al. 2001; de Groot, Hjeltnes et al. 2003; Hicks, Martin et al. 2003; Devillard, Rimaud et al. 2007), but what is less clear is the locus of improvement - central (eg cardiac output) or peripheral (oxygen extraction, vascular changes). Current knowledge suggests peripheral changes (Stewart, Tarnopolsky et al. 2004). This area provides fertile grounds for future research, recognising the difficulties in measuring cardiac output during exercise.

Muscle weakness is a common problem in SCI, and this limits many activities of daily living, such as transfers, wheelchair propulsion (especially up inclines), and working overhead. Muscle weakness is often accompanied by pain in the shoulder joint and girdle (Nawoczenski, Ritter-Soronen et al. 2006), but paradoxically exercise seems to diminish perceived pain (Dyson-Hudson, Sisto et al. 2007). The main cause for the pain syndromes is insufficient shoulder muscle strength (Pentland and Twomey 1994). Based on these observations, the inclusion of resistance exercises in SCI training would seem to be essential. Recent studies utilising novel approaches to ergometer training (Fitzgerald, Cooper et al. 2004) suggest that playing computer games while exercising has an increased effect over standard ergometry. The evidence also seems to suggest that high intensity exercise is required to have any strength effect, (Davis and Shephard 1990; Davis, Plyley et al. 1991). However, these authors note that arm cranking produced limited benefits in all but shoulder extensor and elbow flexor muscles and had no effect on shoulder girdle muscles.

More recently, (Hicks, Martin et al. 2003) utilised a RCT in a study to examine the effects of a nine-month exercise program (twice-weekly sessions) on a sample of 34 volunteer subjects (age 19-64, C4-L1; ASIA A-D). Subjects were randomly assigned to treatment (n= 21) and control (n=13) groups. Control subjects were offered a health counselling program during the training period and an invitation to join the exercise group following the study period. The exercise sessions included warm-up/stretching activities, aerobic activities (30 min arm ergometry at 70% MHR or 3-4 on Borg perceived exertion scale), and resistance exercise (free weights, pulleys, weight machine in circuit arrangement). Subjects were assessed on a number of criterion measures, including strength, ergometer work capacity, QoL and subjective well-being, at three, six, and nine months. Only 11 of the exercise participants completed the training (a 50% drop-out figure).

The pre-exercise tests showed no significant differences between groups in age, sub-maximal arm ergometry performance, muscle strength, or psychological well-being. Following training, the exercise group had significant increases in sub-maximal arm ergometry power output (81%; $P<0.05$), and significant increases in upper body muscle strength (19-34%; $P<0.05$); no significant changes occurred in controls. Exercise participants reported significantly less pain, stress and depression after training, and scored higher than control subjects in indices of satisfaction with physical function, level of perceived health and overall quality of life ($P<0.05$). Exercise adherence (per cent of prescribed sessions attended) in those subjects who completed the 9 months of training was 82.5%, but there was a high attrition rate.

The fact that significant improvements can result from high intensity aerobic and strength activities comes as no surprise. It has been the basis of physical therapy in SCI for decades. Many studies have been published in the broad medical, health, and sport literature to support regular physical activity for SCI populations (Davis, Plyley et al. 1991; Jacobs, Nash et al. 1997; Hjeltnes and Wallberg-Henriksson 1998). However, the difficulty in interpreting evidence from studies of exercise in SCI populations has recently been described (Valent, Dallmeijer et al. 2007). In a systematic review of the literature, the authors concluded that the quality of the studies examined was poor (i.e. no RCTs), and that only tentative conclusions could be reached about training effects.

In terms of the level of activity required for significant gains in aerobic capacity and strength, various authors (McLean 1992; Bizzarini, Saccavini et al. 2005; Myslinski 2005) have suggested that strengthening and aerobic rehabilitation programs for patients with sub-acute SCI should be limited to four weeks, followed by an independent maintenance exercise program. For post-acute fitness maintenance it is suggested that moderate intensity exercise performed 20-60 min per day, at least three days per week for a minimum of six weeks is effective for improving C-V fitness (Warburton, Sproule et al. 2006). There is some evidence that there is an increased susceptibility to isometric contraction-induced muscle injury in long-term SCI (Bickel, Slade et al. 2004).

The American College of Sports Medicine (ACSM) has recommended training frequencies, intensities and durations in SCI (Figoni 1997). They generally follow advice to the able-bodied population but generally recommend three to five weekly exercise sessions of 20-60 minutes duration and an intensity of 50-80 per cent VO2 peak. This correlates with a HR response of 50-80 per cent peak HR.

For strength training, it is suggested that the program include three sets of 8-12 repetitions per exercise movement for two sessions per week at moderate-high intensity using free weights, weight machines and elastic tubing and bands (Jacobs and Nash 2004). However, this will vary according to the health status of the individual with SCI, and trainers should begin conservatively and carefully observe loads and responses and adjust accordingly.

The ACSM does suggest that over-use pain and injury should be avoided by careful monitoring of exercise and gradual increases in intensity supervised by trained personnel. This advice suggests that hospital and community fitness staff should have some training in the specific requirements of people with SCI undertaking exercise.

6.2.3 Functional electrical stimulation (FES)

In many cases of SCI, the motor units serving muscle below the level of the lesion remain intact, but spasticity, muscle wasting, and C-V decline in the lower limb are caused by inactivity. For many years, the clinical answer has been the use of passive stretching and mobility exercises performed by a therapist. However, from the early 1980s increased interest centred on the use of artificial stimulation to produce muscle contraction. The paradigm was called Functional Electrical Stimulation (FES) and its development was largely due to the advent of the desk-top computer and design of purpose-built isolated stimulators. The use of FES has grown dramatically in clinical applications over the past 25 years, in both the range of specific sites being stimulated, and the inclusion of increasingly complicated orthoses to assist standing and walking.

The range of activities includes

- Site-specific stimulation of arms and legs
- Leg cycling
- Leg exercise and arm-assist
- Rowing/kayaking
- Arm ergometry
- Standing, and
- Treadmill walking

It is commonly held that direct stimulation of the target muscle accounts for the contraction, but in fact it is stimulation of the peripheral nerve serving the muscle that produces purposeful contraction (Glaser, Mathews et al. 1997). For this reason, FES works in patients where the lower motor neuron is intact. Surface electrodes are used to activate the muscle, with the voltage/current regulated by a stimulator, controlled by various stimulation patterns in a small computer. Creasey recently reviewed the current practice in FES (Creasey, Ho et al. 2004), while Peckham (Peckham and Gorman 2004) has given some insights into future possibilities using the technique, including bionic gloves, implantable systems, bladder prostheses, and various locomotion devices.

Some guides have been published in an effort to standardise FES procedures (Teeter and Brown 1997).

The purpose of using FES is

- Exercise previously inactive muscles and joints to offset atrophy
- Develop strength and fitness in combination with other activities
- Activate spinal circuits as a prelude to walking
- Develop assisted walking systems to increase independence and mobility in SCI.

The simplest and most widely used activity is recumbent cycling, in which an embedded controller coordinates contractions of the quadriceps, hamstring, and gluteus muscles to produce movement with cadence and stimulation intensity controlled by feedback from position sensors in the pedals. In some circumstances, such as severe muscle atrophy, the exercise is preceded by a period of muscle strengthening of the quadriceps muscle (Dudley, Castro et al. 1999; Jacobs and Nash 2004). Despite the low level of general conditioning, FES cycling has been demonstrated to improve fitness and muscle bulk in many reported studies (Hooker, Figoni et al. 1992; Hooker, Scremin et al. 1995; Mohr, Anderson et al. 1997; Mutton, Erika Scremin et al. 1997; Mutton, Scremin et al.

1997). In tetraplegics, marked left ventricle atrophy has been reversed (Nash, Bilsker et al. 1991), and peripheral circulation improved (Gerrits, de Hahn et al. 2001). Other benefits to have been reported include improved insulin resistance (Mohr, Dela et al. 2001; de Groot, Hjeltnes et al. 2003; Phillips, Stewart et al. 2004; Mahoney, Bickel et al. 2005), less bone and joint degeneration (Nash, Tehranzadeh et al. 1994), improved body composition (lean mass and body fat) (Hjeltnes, Aksnes et al. 1997). These gains are further enhanced when upper extremity exercise is combined with FES-induced leg-cycling (Mutton, Scremin et al. 1997; Thijssen, Heesterbeek et al. 2005). Such gains also occur in as little as four weeks of training (Heesterbeek, Berkelmans et al. 2005; Thijssen, Ellenkamp et al. 2006). As it transpires, there is some evidence that even passive cycling of paralysed limbs increases blood flow (Ballaz, Fusco et al. 2007).

The physiological response to FES exercise is different to arm ergometer exercise. Arm exercise results in faster VO2 kinetics greater increases in HR and lower post-exercise lactates than FES cycling (Barstow, Scremin et al. 2000).

Other activities that have utilised FES include arm rowing (Wheeler, Andrews et al. 2002), reciprocating gait orthoses (Solomonow, Reisin et al. 1997), and kayaking (Bjerkefors, Jansson et al. 2006; Bjerkefors, Carpenter et al. 2007). All have shown fitness gains following a training period.

FES has also been used extensively to achieve walking in complete and incomplete SCI, using sophisticated stimulation patterns to drive neuroprostheses (Stein, Gordon et al. 1992; Gallien, Brissot et al. 1995; Stein, Hayday et al. 2005). There is now one commercial FDA-approved FES walking system available (Parastep; Sigmetics, Inc, Chicago, Illinois, USA). Apart from the clinical benefit from improved potential for independent walking, many of these systems are in the developmental stage and their impact on health is as yet unknown.

In summary, FES is now an accepted part of both clinical therapy and community fitness settings in many parts of the world. Moderate to vigorous exercise intensity training is effective in improving cardio-vascular fitness, muscle strength, bone strength, lipid and insulin metabolism, reduction in perceived pain, and quality of life. Much of this evidence is based on non-randomised trials. Future research could make better use of FES, particularly with the opportunity to develop research protocols which are multi-centred across Australia and that involve segregated fitness settings and community programs.

7. EXERCISE PRESCRIPTION

This section briefly summarises some of the key issues reported to be essential considerations for the development of exercise prescriptions for people with SCI. It includes references to several evidence based reviews and other key publications. Given the rapidly changing evidence base only literature published since 2002 has been included.

The key considerations identified in the exercise prescription literature include:
- Understanding of relative and absolute **contraindications** for testing and training people with SCI
- Appropriate exercise testing and training of persons with SCI to be based on the individual's exercise capacity as determined by **accurate assessment** of the spinal lesion. For example, level and completeness of injury will affect cardiac acceleration, maximal heart rates, capacity for neuromuscular activation by means of electrical stimulation. Other considerations include joint range of motion, spasticity, skin integrity, pain, equipment, psychological factors, home environment etc
- **Setting objectives** – e.g. inclusion of client goals such as strength, weight loss, change in body composition
- **Monitoring** – by client and through testing
- **Environmental considerations -** to be safe, supervised, and welcoming (particularly when in a community setting)
- **Pain** minimisation e.g. stretching, slow build up of intensity etc
- Awareness and management of increased **risks** related to systemic dysfunction following the spinal injury e.g. autonomic dysreflexia, musculo-skeletal injury (fracture, joint dislocation, overuse syndrome), hypotension, thermal dysregulation
- **Inclusion of education and counselling** e.g. re benefits, motivation, planning and supports, referral for psychological evaluation if indicated
- A **team approach to prescription** i.e. using a medical practitioner, physiologist and therapist: and early supervision of the program by a clinical exercise physiologist or therapist (e.g. (Schaefer, Ehrman et al. 2003), p517).

While there is little research to date to support **specific guidelines** (Myers, Herbert et al. 2002), p60) several evidence based **general guidelines** have been formulated. For example, the American College of Sports Medicine general guidelines includes sections on:
- Exercise modes e.g. swimming, wheeling overground or treadmill etc
- Regulation of exercise e.g. heart rate monitoring, perceived exertion scale
- Environment e.g. temperature, humidity, fluids
- Safety e.g. supervision, transfers to equipment, assistance to perform exercise, follow disability specific precautions (e.g. monitor BP, repositioning, use of stockings or binders), prevent and treat upper limb overuse syndromes, empty bladder/collection devices (see also (Schaefer, Ehrman et al. 2003))
- Follow up i.e. with appropriate health personnel re information about medical complications
- Training principles: specificity, overload, progression, regularity (Myers, Herbert et al. 2002).

More specific **exercise prescription** specifies the mode, frequency, intensity and duration of activity for a person with known abilities and needs. Examples of this approach are illustrated in:
- Components of the Beginning and Advanced Exercise Prescription for Persons with Spinal Cord Dysfunction. ACSM. (Myers, Herbert et al. 2002)

- Cardiovascular, resistance, and flexibility exercises. (Schaefer, Ehrman et al. 2003)

Other useful references and resources relevant to guidelines for physical activity are:

DeTurk W, Cahalin L 2004
Cardiovascular and Pulmonary Physical Therapy: An Evidence-based Approach McGraw Hill see p404 onwards

Frontera W, Slovik D, Dawson D 2006
Exercise in Rehabilitation Medicine
Ch 13: Nash M. Includes topics: Exercise for Persons With Spinal Cord Injury, Exercise Risks for Persons With Spinal Cord Injury, Medications That May Influence Exercise Performance After Spinal Cord Injury

NCPAD: Exercise and Fitness: Resistance Training Guidelines for Spinal Cord Injury
http://www.ncpad.org/exercise/fact_sheet.php?sheet=107&section=810
Also includes Guidelines for Wheelchair Users, and General Safety Guidelines for Wheelchair Users

NSW Department of Health, Sydney, Australia.
http://www.physiotherapyexercises.com/ This website currently contains over 300 physiotherapy exercises appropriate for people with spinal cord injuries. The website is still developing and funds have recently become available to include additional exercises appropriate for people with different types of neurological disabilities, including traumatic brain injury, stroke and multiple sclerosis.

Skinner J 2005
Exercise Testing and Exercise Prescription for Special Populations Lippincott Williams & Wilkins. Philadelphia See p205-219 Exercise therapy.

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