

# 45. *Spinal cord injury*

## *Author*

*Nils Hjeltnes, MD, PhD, Spinal Cord Injury Rehabilitation Department, Sunnaas Hospital, Nesoddtangen, Norway*

## *Summary*

Physical activity and exercise following a spinal cord injury is a central part of the rehabilitation programme for everyone with a spinal cord injury. As in individuals with normal function, the best form of rehabilitation/physical activity depends on such factors as age, gender and fitness, etc. However, the level and extent of the injury as well as how much time has passed since the injury are of even greater importance. Patients should be mobilised as soon as medically possible after a spinal cord injury. The initial treatment is passive, e.g. stretching muscles, mobilising joints and removing mucus. This is followed by an active training programme that incorporates individual training for the purpose of improving aerobic fitness, muscle strength, coordination and balance. Much of the training is similar to that recommended for individuals with normal function except that it is of a different intensity and modified to the individual patient. Both the spinal cord injury patient and the physiotherapists managing his or her rehabilitation must know how to avoid and prevent complications during training. Physiotherapists must also be fully aware of the possibilities available to spinal cord injury patients so as to be able to help the patient improve his or her health and physical fitness. Recent epidemiologic studies indicate that there is a relatively large number of patients with incomplete spinal cord injuries. Consequently, it is vital to acquire new knowledge on how these individuals can best train, not just for the purpose of improving aerobic fitness and muscle strength, but also to learn how to do “old activities with new muscles”.

## *Introduction*

A spinal cord injury destroys the neural connections between the cranial part of the central nervous system and the spinal cord caudally of the damaged area. Depending on the localisation and extent of the injury, this usually leads to a varying degree of muscle paralysis and lack of sensation in addition to a reduced control of bodily functions (e.g. urination, defecation and sexual function), blood pressure and body temperature. A spinal cord

injury is either traumatic because of a traffic accident, fall, work-related injury, sports injury or violence, or atraumatic as a consequence of an infection, circulation disorder or tumour (benign or malignant). The injury may also be congenital (inherited or caused at birth) or caused by medical or surgical intervention.

The following section focuses on physical activity and training for people with a spinal cord injury from around 6 months after the occurrence of the injury.

## *Level and extent of injury*

While the spine has 7 cervical, 12 thoracic, 5 lumbar and 5 sacral vertebrae, the spinal cord has 8 cervical, 12 thoracic, 5 lumbar and 5 sacral *spinal cord segments*. Each segment forms a pair of *spinal nerve roots* that innervate the myotomal muscles and consist of sensory fibres from a *dermatome on the skin*. On this anatomical basis, it is not difficult to localise the spinal cord injury level with a clinical neurologic examination.

The level of the neurologic injury is defined on the basis of the degree of normal function found in the caudal spinal cord segment (1, 2). A spinal cord injury that causes paralysis in both arms and legs is called *tetraplegia*. A spinal cord injury that causes paralysis in the legs and torso (truncus) is called *paraplegia*. There is reason to classify patients with the lowest level of spinal cord injury, i.e. a conus medullaris injury, and patients with a cauda equina injury into the same category, i.e. the conus-cauda syndrome. Common for patients with conus-cauda injuries is paralysis of the legs, a dysfunctional urinary bladder and rectal muscles plus pronounced sexual dysfunction.

The cross-sectional extent of a spinal cord injury is just as important as the level of the injury as regards the ability to function properly after a spinal cord injury as classified by the American Spinal Injury Association's (ASIA)\* Impairment Scale, Class A to E. Patients classified as:

**AIS-A** have no motor or sensory function below the spinal cord injury level.

**AIS-B** have impaired sensory function below the injury level.

**AIS-C** have impaired motor and sensory function below the injury level.

**AIS-D** have a certain motor function preserved (muscle grade 3 or more on a scale from 0 to 5) in 50 per cent of the muscles below the injury level.

**AIS-E** have insignificant neurologic impairment as a consequence of the spinal cord injury (1).

\* Original specification of [www.asia-spinalinjury.org/contact/](http://www.asia-spinalinjury.org/contact/) reads:

- A** = Complete: No motor or sensory function is preserved in the sacral segments S4–S5.
- B** = Incomplete: Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4–S5.
- B** = Incomplete: Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.
- D** = Incomplete: Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.
- E** = Normal: motor and sensory functions are normal.

AIS-A is considered a complete injury, i.e. complete loss of motor and sensory function below the defined injury level. AIS-B to AIS-D represents an incomplete injury where AIS-B means that the injured person still has a complete motor dysfunction, but an intact sensory function. In order for an injury to be considered incomplete, the injured person must have sensory and/or motor function in the lowest sacral spinal cord segment, i.e. sensation and/or controlled rectal motor function.

## *Epidemiology*

Epidemiologic studies show that even if the annual incidence of spinal cord injuries varies, it is relatively stable over a longer period of time. In Norway, the number of new traumatic spinal cord injuries needing specialised rehabilitation was 16.5 in 1 million in 1974 (3). From 2001 to 2004, this number was between 12 and 18 per 1 million and year (data obtained from NordiskRyggmargskadeRegister). A Nordic Spinal Cord Injury Council has been established and is updated on an annual basis ([www.nscic.se](http://www.nscic.se)).

The most common cause of traumatic spinal cord injuries is road accidents, although this has lately been matched by injuries from falls. Injuries from free-diving have become less common, while injuries as a result of violence are on the rise. Between 20 and 25 per cent of those afflicted are women. No Norwegian prevalence studies exist, but studies carried out outside of Norway show an incidence of between 200 and 1,000 per 1 million inhabitants. This means that there are between 1,000 and 5,000 people in Norway with a permanent functional impairment as a consequence of a spinal cord injury. Recent studies indicate a somewhat lower prevalence in Sweden than Norway. There are no comparative international studies on the prevalence of spinal cord injuries.

In Norway, an estimated annual figure of 60 patients with atraumatic spinal cord injuries require the same rehabilitation and training programme as patients with traumatic spinal cord injuries. However, this figure does not include patients with spinal cord injuries caused by cancer (and metastasis). It is assumed that the same prevalence exists in other Nordic countries.

## *Treatment of traumatic spinal cord injuries*

The treatments and primary rehabilitation methods employed nationally and internationally after a traumatic spinal cord injury of a cross-sectional nature are usually centralised at so-called comprehensive spinal units. The comprehensive spinal units are either made up of emergency and rehabilitation departments at the same hospital or separate institutions. Most importantly, these units have specialist expertise, which is a guarantee that the treatment and rehabilitation programmes offered to patients are on a par with high-quality international standards. Highly specialised and competent spinal cord injury departments cooperate with other specialists (urology, plastic surgery) throughout the lifelong treatment of spinal cord injuries. Other organisations and institutions are also involved in the follow-up process such as primary healthcare and physiotherapy clinics. These offer training camps and physical skills programmes for patients with new or old injuries.

A more thorough description of emergency treatment and primary rehabilitation of spinal cord injuries falls outside the scope of this chapter. The “father” of today’s treatment and rehabilitation of spinal cord injuries, Sir Ludwig Guttmann, said the following back in 1945: “Rehabilitation after spinal cord injuries seeks the fullest possible physical and psychological readjustment of the injured person to his permanent disability with a view to restoring his will to live and working capacity” (4). The cutting-edge expertise that is offered by spinal cord injury treatment units contributes to achieving this objective (5).

## *Effects of spinal cord injuries on level of activity*

A spinal cord injury usually involves a dramatic change in the injured person’s ability and possibility to be physically active. Naturally, the level and extent of the injury is of utmost importance in this context. A person with complete tetraplegia with a damaged respiratory centre (nucleus phrenicus) may be lifetime dependent on a ventilator and thereby restricted to passive physical training. However, a person with an incomplete low spinal cord injury (conus injury) could have an intact skeletal muscle function, but a restricting body dysfunction with a better chance of physical activity regardless of the level of injury than a person with a similar, but complete injury.

### *Neuromuscular function/spasticity*

After a spinal cord injury, spasticity imitates spinal reflexes to replace normal muscle activity. Spasticity is a syndrome that increases resistance to rapid passive movements, involuntary clonic and tonic muscle spasms, conductive time delay, synergist and antagonist coactivation and reduced strength (6). At the same time, these spasms are a manifestation of what “the spinal cord can manage on its own” and hence, should only be treated if functionally restrictive for the injured person (7).

### *Lung function*

Lung function and lung capacity are strongly linked to the level of the spinal cord injury (8–10). Persons with an upper cervical spine injury may need the lifelong support of a ventilator. Some patients need help breathing for certain periods of time and therefore need access to a ventilator or similar equipment in their home (CPAP/Bi-PAP). Tetraplegic patients generally suffer from sleep apnoea, even during the chronic stage of their injury (11). However, the lung capacity of patients needing respiratory assistance is seldom a restrictive factor for physical activity during the chronic stage of their injury, regardless of the level of injury. This is evident from tests using an arm-pedalled bicycle where the respiratory minute volume during maximal exertion continued to increase at the same time that a decrease in the oxygen uptake capacity was noted.

### *Autonomic regulation weakness*

A complete cervical spinal cord injury also destroys the communication between the superior autonomic centre of the brain and the sympathetic intermediolateral nucleus membrane of the spinal cord and corresponding parasympathetic nucleus membrane in the sacral portion of the medulla. This not only of consequence to controlled body functions such as urination, sexual function and defecation, but also to the regulation of heart rate, blood pressure and body temperature.

By using industrial physiological techniques and subjecting a person with a spinal cord injury to maximal load on an arm ergometer while measuring the person's heart rate, blood pressure, maximal oxygen uptake and lactic acid production, it has been possible to show that the heart rate in patients with complete tetraplegia hardly ever exceeds 125 heart beats per minute at maximal load (12, 13). Instead, physical exertion results in a drop in blood pressure and a disproportionate increase in body temperature relative to the low, but maximal load that tetraplegic patients can cope with (14). Some tetraplegic patients will always have a problem with their blood pressure, even when sitting in a wheelchair.

Patients with high paraplegia respond in very much the same way, but can usually increase their heart rate to a normal maximal rate (13) and therefore do not suffer to the same extent from drops in blood pressure due to exertion. However, this group of patients does not suffer from the same rise in blood pressure caused by exertion as non-disabled individuals. The blood-pressure response during physical load is fairly normal in those with spinal injuries where the level of injury is below the tenth (Th10) thoracic vertebrae. The cardiac muscle generally has an overcapacity compared with the load to which a disabled person is subjected in the chronic stage of a spinal cord injury. The load placed on the cardiac muscle of a tetraplegic person is so insignificant that the cardiac muscle decreases in size (hypotrophies) due to the insufficient level of physical activity, low venous back-flow and low blood pressure (15). A varying degree of impaired autonomic regulation may also exist in patients with incomplete cervical injuries. There are numerous examples of persons with mild spasticity and incomplete tetraplegia (ASIA-D) who become pale and feel sick as a result of physical exertion long after the injury occurred.

### *Autonomic dysreflexia*

Autonomic dysreflexia is an autonomic sympathetic “overactivity syndrome” (16). This syndrome is primarily seen in patients with a complete injury above the Th6 level, but is also found in individual patients down to an injury level of Th10. The overactivity syndrome is characterised by high blood pressure with headaches, bradycardia, goose bumps, perspiration above and below the injury level and facial redness which may occur in conjunction with physical activity. The vasoconstriction, i.e. narrowing of blood vessels, especially the visceral vessels, results in a clear rise in blood pressure that can be life-threatening or used by tetraplegic persons to prevent an unwanted fall in blood pressure during exercise (boosting). The triggering factor, whether an overfull bladder, urinary tract infection or anything else that activates the spinal cord below the injury level, should nonetheless be removed without delay.

### *Metabolic function*

Body composition changes following a spinal cord injury at both the macro and micro level. These changes (reduced bone density and muscle mass plus increased body fat) are a consequence of the metabolic changes caused by the spinal cord injury and the physical inactivity created by the paralysis (17). Muscles are metabolically active organs and a reduced muscle mass means that nutrients and other waste products from the metabolic system remain in the blood for a longer period of time than in healthy people.

Studies have shown that persons with a spinal cord injury have a lower glucose tolerance and that insulin resistance is predominantly caused by a reduced muscle mass (18). However, the muscle cells below the injury level have a normal glucose uptake capacity when stimulated by insulin or functional electrical stimulation although most of the muscle fibres are very small, i.e. type 2b fibres (19). In addition, persons with protracted spinal cord injuries appear to have an unfavourable cholesterol profile with low HDL and high LDL levels (20). These verified metabolic changes are linked to the results of descriptive epidemiological studies which signify a predominance of obesity, insulin resistance, Type 2 diabetes and coronary artery disease among people with a protracted spinal cord injury (21).

### *Other conditions*

Like people in good functional health, the level of physical activity in people with impaired functional health is dependent on age, gender, psychosocial and environmental conditions. There is currently no cure for spinal cord injuries and since there are only limited resources to support treatment, rehabilitation and lifetime monitoring, it is vital that expert professionals, researchers, politicians as well as the spinal cord injury patients themselves prioritise those areas that need further development. In an American interview study, more than 96 per cent of the spinal injury patients said that physical activity was important to achieve functional improvement (22). Around 57 per cent of the interviewees had the possibility of exercising, while only around 12 per cent were able to exercise with the assistance of a personal trainer or physiotherapist. The same study showed that tetraplegic patients

missed their finger and hand function, while paraplegic patients would like to have their sexual function restored to normal. Both tetraplegic and paraplegic patients would prefer to have urinary and defecation functions restored more than the ability to walk (22).

## *Exercise, effects and special conditions*

Normal physical activity and exercise after a complete spinal cord injury entail using muscles not affected by the injury, which in the case of tetraplegia means arm and shoulder muscles with the addition of trunk muscles for paraplegic patients and leg muscles for conus injuries and other incomplete injuries. It is well documented in a number of controlled studies that various methods of arm training (arm cycling using an arm ergometer, wheelchair ergometer, manual wheelchair training on a treadmill or rowing) and various training programmes (interval training) designed to achieve maximal oxygen uptake ( $\text{VO}_2$  max/peak  $\text{VO}_2$ ) or a specific percentage increase in the heart rate increase the maximal load and the body's ability to cope with lactic acid. A higher aerobic fitness level lessens the load placed on the heart during daily activities (23).

General physical training also involves training the respiratory muscles. In tetraplegic patients, the diaphragm is more than a respiratory muscle. It is also an equilibrium muscle when the patient is sitting and can sometimes become fatigued by having to carry out two functions at the same time (24). A person with high tetraplegia (level C6) has a significantly reduced vital capacity and the daily sitting positions of a person with such a high level injury should not engage the diaphragm to act as a postural muscle. During physical training, such as the use of an arm ergometer, the trunk of the patient should be fixated with a trunk belt to prevent the diaphragm from having to carry out two functions. Hence, it is possible to exercise although the fixation of the trunk is vitally important as it could otherwise lead to injury with negative consequences for other daily functions.

## *Skin*

The patient's skin must be carefully monitored, which is a task that can gradually be shifted over to the patient, who can do it on his/her own using a mirror. At first sign of red pressure marks or abrasions on the skin, an expert adviser should immediately be contacted, bedding and seat cushioning checked and, if required, the pressure unloaded. Unloading pressure is very important during treatment and to prevent pressure sores (25). Some spinal units have the ability to register the pressure that individual patients are subjected to when sitting or lying and as a result, the bedding and seat cushioning can be made to order which is ideal. There are also ready-made, high-quality mattresses and seat cushions to buy which only require minor adjustments.

In addition, a change of position stimulates the vascular reflexes that regulate the blood flow through the skin. Using electrical muscle stimulation, the muscle mass can be increased in areas that are subjected to pressure (gluteal muscles) and so, give added protection, for example around the hips where the skin is close to the bone.

### *Urinary tract and urination*

Some individuals with spinal cord injuries have problems with incontinence when carrying out a physical activity (26). “Training is not fun when you always end up peeing in your pants”, announced a spinal patient whose problem was later solved and who went on to become an Olympic Weightlifting Champion. Irrespective of how a patient’s bladder is emptied, many spinal cord patients end up with urinary tract infections and a limited ability to carry out physical activity or training for certain periods.

### *Gastrointestinal tractus – alimentary canal*

Problems defecating after a spinal cord injury are aggravated by physical inactivity, not least due to the reduced activity and toning of the abdomen muscles. The severity of the problem varies from individual to individual, but is generally dependent on the level and extent of the spinal cord injury. Of spinal cord patients, 30 per cent feel that problems defecating are more troublesome than those associated with urination or sexual function (27). The nutritional regimen, food patterns and physical activity are considered to be important to the functioning of the intestine.

### *Contracture prophylaxis*

Joint mobility should be maintained in the early stages of an injury to avoid joint stiffness and contracture in joints that are not used, irrespective of muscle tonus (muscle tension). In paralysis with reduced muscle tonus, a daily programme of activities is usually sufficient, but joints subjected to a local trauma or oedema need to be moved 2–3 times a day. In special cases (complete injury), taping the patient’s hands or using modified fixation plates to fixate the patient’s finger joints in a better (more functional) handgrip position is an initial possibility. Also, the use of plates preventing the development of club foot can be beneficial.

### *Reduced bone mineral density (osteopenia)*

Bones that are neither subjected to gravity nor muscular strength lose strength and mineral density (28, 29). The rapid decalcification that occurs in the first three months after a spinal cord injury increases the risk of severe *hypercalcemia*. Hypercalcemia usually affects boys or young men with tetraplegia or high tetraplegia (above Th5) who were very physically active (athletes) prior to the accident, although not patients with incomplete injuries (30).

Injuries of the central nervous system with pronounced paralysis increase the risk of decalcification around the joints, *periarticular ossifications* (PAO). This is an inflammatory reaction that primarily occurs adjacent to large joints (laterally around the hips and medially around the knees, ankles and sometimes the elbows). This complication is predominant in patients with a complete spinal cord injury, but seldom in children. The patient’s general health is affected by fever, elevated inflammation test levels (CRP and SR) and an increase in the amount of alkaline phosphates (ALP).

No matter what type of treatment is offered, a massive decalcification of the long femur bones below injury level is unavoidable. There are currently no long-term studies indicating that standing training exercises increase the bone density after a spinal cord injury. However, it is documented that electrically stimulated leg cycling carried out by tetraplegic patients resulted in an increased bone density, particularly around the knee joint (31). *Consequently, spontaneous fractures* in the lower extremities are a common long-term complication in spinal patients and ought to be treated along the same principles as spontaneous fractures in persons with no functional impairments, but extra care should be taken when casting a fracture so as not to subject the skin or nerves near the surface to pressure.

Defective spinal position is also common in persons with spinal cord injuries. However, new surgical procedures to treat the acute phase of an injury reduce the risk of developing severe gibbus (spinal hump) or scoliosis. Because of changes in the paravertebral muscle tonus, weakened abdomen muscles, a lot of sitting combined with a poor sitting position, the spine will have to be checked on a regular basis for the rest of the spinal patient's life. Surgery for the correction of secondary scoliosis is required when the scoliosis is a hindrance to function or exceeds an angle of 35–40 degrees.

### *Diet and nutrition*

The diet of those with spinal cord injuries must be adapted to a changed metabolism. The daily calorie intake is lower than in healthy persons with no functional impairment, usually due to physical inactivity. However, this does not necessarily mean that the individual's appetite is reduced and obesity is consequently a real problem for many patients. There are currently no studies recommending a special diet for this group of patients, which is why the diet recommended for healthy persons with no functional impairment applies, i.e. a nutritional low-calorie diet. To-date, no documentation can verify that spinal patients would benefit from nutritional supplements even though a lack of nutrients appears to prolong the healing of pressure sores (32).

### *Pain*

Chronic pain is a serious problem after a spinal cord injury and a frequent obstacle to physical activity and training. The prevalence of pain varies from study to study, but an average of 65 per cent of spinal injury patients experience chronic pain, one-third of whom were found to have pronounced pain (33). The main difference seems to be whether the pain is nociceptive or neurogenic or localised above, in the centre of or below the spinal cord injury level. Psychological and social factors undoubtedly play an important role too. It is difficult to treat chronic pain (33). When medicinal and/or surgical treatment is not enough, pain management strategies, cognitive therapy and support from other spinal patients is of vital importance.

### *Syringomyelia*

Syringomyelia is a very problematic condition in spinal cord injury patients (34). Post-traumatic syrinxes (spinal cord cysts) form at spinal cord injury level in up to 30 per cent of all spinal patients. However, there is no reason for a surgical procedure before the patient experiences severe pain or loses muscle strength and sensitivity of the skin. Diagnosis is usually clear-cut using magnetic resonance imaging, which shows whether a cyst has formed or spread. Patients with syringomyelia are sometimes recommended to abstain from physical training such as weight lifting.

### *Hand surgery*

Reconstructive hand surgery can lead to and improved finger and hand function in tetraplegic patients (35). Hand surgery is most beneficial for patients with level C6 injuries where initial surgery is aimed at developing the primary stretch function of the elbow followed by key grip surgery between the thumb and index finger. Hand surgery can also result in a patient with level C5 injuries regaining his/her wrist function. Patients with level C7 injuries may also regain finger flexibility. This means added opportunities with respect to physical activity and training.

### *Orthopaedic aids*

A range of plates and orthoses have been developed for the improvement of walking in paraplegic patients. Standard plastic or metal orthoses for knees, ankles or feet plus knee locks and foot/foot joint plates are generally available. A so-called Parawalker and Reciprocating Gait Orthosis can be combined with an electrical function simulation of a hybrid orthosis to improve walking in paraplegic patients (36–39). Despite the use of a mobility aid, it is very energy consuming for a paraplegic patient fitted with plates to walk upright. The walk pattern is slow and many follow-up studies have shown that patients with this type of orthoses would rather use a wheelchair on a daily basis. At any rate, it is recommended that the plates are used in training in an upright position as this could have long-term benefits for the entire body.

## *Conclusion*

It is hoped that future technical developments will lessen the extent of a spinal cord injury in the acute stage and provide better opportunities for supporting weakened body parts in the rehabilitation phase. Around the world, key data is accumulated systematically in so-called spinal cord injury registries such as the Nordic Spinal Cord Injury Council for the purpose of improving treatments offered to those with spinal cord injuries. However, it is still not possible to fully cure a spinal cord injury, and preventive measures, rehabilitation and access to daily physical activity and training are extremely important.

## References

1. Ditunno JF, Young W, Donovan WH, Creasy G. The international standards booklet of neurological and functional classification of spinal cord injury. *Paraplegia* 1994;32:70-80.
2. Maynard jr FM, Bracken MB, Creasey G, Ditunno jr JF, Donovan WH, Ducker TB, et al. International standards for neurological and functional classification of spinal cord injury. *Spinal Cord* 1997;35:266-74.
3. Gjone RN, Nordlie L. Incidence of traumatic paraplegia and tetraplegia in Norway. A statistical survey of the years 1974 and 1975. *Paraplegia* 1978-79;16:88-93.
4. Guttmann L. New hope for spinal sufferers. Ludwig Guttmann. Reproduced from *Medical Times*, November 1945. *Paraplegia*. 1979;17:6-15.
5. Jones L, Bagnall A. Spinal injuries centres (SICs) for acute traumatic spinal cord injury. *Cochrane Database Syst Rev* 2004;(4):CD004442.
6. Young RR. Spasticity. A review. *Neurology* 1994;44:S12-20.
7. Kirshblum S. Treatment for spinal cord-injury related spasticity. *J Spinal Cord Med* 1999;22:199-217.
8. Borel CO, Guy J. Ventilatory management in critical neurologic illness. *Neurol Clin* 1995 Aug;13:627-44.
9. Carter RE. Respiratory aspects of spinal cord injury management. *Paraplegia* 1987;25:262-6.
10. Anke A, Aksnes AK, Stanghelle JK, Hjeltnes N. Lung volumes in tetraplegic patients according to cervical cord injury level. *Scand J Rehab Med* 1993;25:73-7.
11. Biering Sørensen F, Biering Sørensen M. Sleep disturbances in the spinal cord injured. An epidemiological questionnaire investigation, including a normal population. *Spinal Cord* 2001;39:505-13.
12. Dallmeijer AJ, Hopman MT, van As HH, van der Woude LH. Physical capacity and physical strain in persons with tetraplegia. The role of sport activity. *Spinal Cord* 1996;34:729-35.
13. Hjeltnes N. Cardiorespiratory capacity in tetra- and paraplegia shortly after injury. *Scand J Rehab Med* 1986;18:65-70.
14. Sawka MN. Physiology of upper body exercise. *Exerc Sport Sci Rev* 1986;14:175-211.
15. Nash MS, Bilsker MS, Kearney HM, Ramirez JN, Applegate B, Green BA. Effects of electrically-stimulated exercise and passive motion on echocardiographically-derived wall motion and cardiodynamic function in tetraplegic persons. *Paraplegia* 1995;33:80-9.
16. Stjernberg L, Blumberg H, Wallin BG. Sympathetic activity in man after spinal cord injury. *Brain* 1984;107:183-98.
17. Hjeltnes N. Physical exercise and electrical stimulation in the management of metabolic, cardiovascular and skeletal-muscle alterations in people with tetraplegia. Stockholm: Department of Surgical Science, Department of Clinical Physiology, Karolinska Hospital; 1998.

18. Aksnes AK, Hjeltnes N, Wahlström EO, Katz A, Zierath JR, Wallberg-Henriksson H. Intact glucose transport in morphologically altered denervated skeletal muscle from quadriplegic patients. *Am J Physiol* 1996;271:593-600.
19. Hjeltnes N, Galuska D, Björnholm M, Aksnes AK, Lannem A, Zierath JR, et al. Exercise-induced overexpression of key regulatory proteins involved in glucose uptake and metabolism in tetraplegic persons. Molecular mechanism for improved glucose homeostasis. *FASEB J* 1998;12:1701-12.
20. Bauman WA, Spungen AM, Zhong YG, Rothstein JL, Petry C, Gordon SK. Depressed serum high density lipoprotein levels in veterans with spinal cord injury. *Paraplegia* 1992;30:697-703.
21. Whiteneck GG, Charlifue SW, Frankel HL, Fraser MH, Gardner BP, Gerhart KA, et al. Mortality, morbidity and psychosocial outcomes of persons spinal cord injured more than years ago. *Paraplegia* 1992;30:617-30.
22. Anderson KD. Targeting recovery. Priorities of the spinal cord-injured population. *Journal of Neurotrauma* 2004;21:1371-83.
23. Janssen TW, van Oers CA, Veeger HE, Hollander AP, van der Woude LH, Rozendal RH. Relationship between physical strain during standardised ADL tasks and physical capacity in men with spinal cord injuries. *Paraplegia* 1994;32:844-59.
24. Sinderby C, Weinberg J, Sullivan L, Lindström L, Grassino A. Electromyographical evidence for exercise-induced diaphragm fatigue in patients with chronic cervical cord injury or prior poliomyelitis infection. *Spinal Cord* 1996;34:594-601.
25. Bell GB. Spinal cord injury, pressure ulcers and support surfaces. *Ostomy Wound Manage* 1999;45:48-50, 52-3.
26. Wyndaele JJ, Madersbacher H, Kovindha A. Conservative treatment of the neuro-pathic bladder in spinal cord injured patients. *Spinal Cord* 2001;39:294-300.
27. Lynch AC, Antony A, Dobbs BR, Frizelle FA. Bowel dysfunction following spinal cord injury. *Spinal Cord* 2001;39:193-203.
28. Biering-Sørensen F, Bohr HH, Schaadt OP. Longitudinal study of bone mineral content in the lumbar spine, the forearm and the lower extremities after spinal cord injury. *Eur J Clin Invest* 1990;20:330-5.
29. Garland DE, Stewart CA, Adkins RH, Hu SS, Rosen C, Liotta FJ, et al. Osteoporosis after spinal cord injury. *J Orthop Res* 1992;10:371-8.
30. Massagli TL, Cardenas DD. Immobilization hypercalcemia treatment with pamidronate disodium after spinal cord injury. *Arch Phys Med Rehabil* 1999;80:998-1000.
31. Mohr T, Andersen JL, Biering-Sørensen F, Galbo H, Bangsbo J, Wagner A, et al. Long term adaptation to electrically induced cycle training in severe spinal cord injured individuals. *Spinal Cord* 1997;35:1-16.
32. Cruse JM, Lewis RE, Dilioglou S, Roe DL, Wallace WF, Chen RS. Review of immune function, healing of pressure ulcers and nutritional status in patients with spinal cord injury. *J Spinal Cord Med* 2000;23:129-35.
33. Ragnarsson KT. Management of pain in persons with spinal cord injury. *J Spinal Cord Med* 1997;20:186-99.

34. Schurch B, Wichmann W, Rossier AB. Post-traumatic syringomyelia (cystic myelopathy). A prospective study of 449 patients with spinal cord injury. *J Neurol Neurosurg Psychiatry* 1996;60:61-7.
35. Friden J. Reconstructive hand surgery after cervical spinal injury. A new method increases the possibilities to reconstruct important functions. *Läkartidningen [Swedish Medical Journal]* 1998;95: 3072-4.
36. Andrews BJ, Baxendale RH, Barnett R. Hybrid FES orthosis incorporating closed loop control and sensory feed-back. *J Biomed Eng* 1988;10:189-95.
37. Bajd T, Andrews BJ, Kralj A, Katakis J. Restoration of walking in patients with incomplete spinal cord injuries by use of surface electrical stimulation-preliminary results. *Prosthet Orthot Int* 1985;9:109-11.
38. Peckham PH, Creasey GH. Neural prostheses. Clinical applications of functional electrical stimulation in spinal cord injury. *Paraplegia* 1992;30:96-101.
39. Yang L, Granat MH, Paul JP, Condie DN, Rowley DI. Further development of hybrid functional electrical stimulation orthoses. *Spinal Cord* 1996;34:611-4.