LOKOMAT Australian Experience: Robotically Gait Assisted Body Weight Support Treadmill Training (BWSTT) – Lokomat Gait Training. Is it an effective and financially feasible treatment?

HyperMED NeuroRecovery Centre – Melbourne, Australia. M. R. Hooper, T. Chamacham 2008.

Abstract: Growing number of adult and pediatric spinal cord injury (SCI) and traumatic brain injury (TBI) cases each year indicates an increasing need for treatment modalities, like Body Weight-Supported Treadmill Training (BWSTT) to assist functional recovery. In addition to treatment of SCI cases, BWSTT has been used for managing other various neurological diseases such as stroke and multiple sclerosis (MS), cerebral palsy and other neurodegenerative states. Robotically Gait Assisted BWSTT (Lokomat) has been shown to be more accurate and financially feasible, compared to the other BWSTT modalities. In this article, we intend to review related articles and evidence to explain the medical and financial feasibility of using this treatment modality for neurological diseases.

Keywords: locomotion, exoskeleton, locomotor training, bodyweight support, robotics

Corresponding author: Malcolm R. Hooper Director Rehabilitation HyperMED NeuroRecovery Australia 13th floor 15 Collins St Melbourne 3001. Email info@hypermed.com.au T: +61 3 9650 3136 F: +61 3 9650 3150.

Introduction:

There are an estimated 50 million Americans affected by diseases or disorders of the spinal cord and brain. The list of disorders includes the following: spinal cord injury, memory loss, addiction, schizophrenia, learning disability, depression, violence, stroke, brain injury, dementia, suicide and many others. More than 90% of the American population has experienced or will experience the effects of a brain-related, mental, emotional or behavioral, disease, disorder or injury at some point in their lives. Spinal cord injuries affect 250,000 Americans, costing more than $10 billion yearly. Head injuries have disabled two million individuals, costing the country $25 billion annually. Strokes affect 500,000 new people every year, costing the national economy $25 billion yearly. Spinal cord and brain disorders impact the American economy in excess of $400 billion a year, on direct health care costs and additional indirect lifetime costs. Individual suffering and loss to society, however, are almost impossible to quantify. Sources: American Paralysis Association and The Dana Alliance for Brain Initiatives.

Bodyweight supported treadmill training (BWSTT) has become a prominent gait rehabilitation method in leading rehabilitation centers throughout the world. This type of locomotor training has many functional benefits but the labor costs are considerable. To reduce therapist effort, Robotically Gait Assisted BWSTT (Lokomat) has been shown to be more accurate and financially feasible, compared to the other BWSTT modalities. Currently 45+ Lokomat systems are in use in large Neurorehabilitation hospitals in the USA and approximately 150 Lokomat systems found in 31 Countries.[39]

In December 2006 HyperMED NeuroRecovery located in Melbourne (Figure 6) installed Australia's first Adult and Pediatric Lokomat systems (Robotic Gait Assisted Body Weight-Support Treadmill Training) providing opportunity for adults and children with gait impairment due to spinal or cerebral motor disorder to improve functional outcomes.

Spinal cord injury (SCI), stroke, traumatic brain injury (TBI), cerebral palsy, multiple sclerosis and other degenerative neurologic states have a devastating impact on those who sustain such injuries, as well as on families

and communities. Ensuring that post injury treatment is as effective as possible is crucial to the successful rehabilitation and quality of life of those who sustain such injuries.

According to the statistical report published by The National Spinal Cord Injury Statistical Centre in 2005, the number of new spinal cord injury (SCI) cases each year is approximately 11,000.[69] Within the group of individuals with SCI, the percentage of incomplete spinal cord injury (ISCI) cases has raised from 45.9% in the 1970s to 55.3% in 2005.[69]

SCI has a significant impact on quality of life, life expectancy and economic burden, with considerable costs associated with primary care and loss of income. The extent of disability after SCI varies greatly, depending on the severity and location of the injury and which nerve fibers are damaged. The resulting neurological deficit can be temporary or permanent, complete or incomplete; one of the primary goals for people with SCI is to improve locomotor function – that is the ability to walk. Traditional therapies and compensation based strategies (such as brace walking) are commonly used to facilitate walking, but do not result in the recovery of walking ability as known before the injury.

Rehabilitation after neurological injury relies on three principles of motor learning. Practice is the first principle. All other things being equal, more functional learning will occur with more accurate practice.[67] Specificity is the second principle. The best way to improve performance of a motor task is to execute that specific motor task. [32] Effort is the third principle. Individuals need to maintain a high degree of participation and involvement to facilitate motor learning.[49,53] These three principles are critical to promoting activity-dependent plasticity (i.e. altering the efficacy and excitation patterns of neural pathways by activating those pathways).[68] With regards to neurological rehabilitation, it is important to emphasize that plasticity occurs in neural pathways that are *active*. Thus, maximizing neuromuscular recruitment during task-specific practice increases the potential for plasticity[27]

Improved locomotor function is often seen in mammals with incomplete and even complete SCI following exercise or rehabilitation, Engesser et al [25]. The most prominent method of gait rehabilitation in current research is bodyweight supported treadmill training (BWSTT). This is a relatively new technique that originated from basic science research on the neural control of vertebrate locomotion.

Spinalized cats can be trained to walk on a treadmill with partial un-weighting of their hindlimbs.[64,44,7] This improvement occurs because, after SCI, the spinal circuitry below the lesion site does not become silent but maintains active, and functional neuronal properties can respond to peripheral input from *below* the level of the injury. It can generate oscillating coordinated motor patterns and is capable of considerable plasticity.[11,23,24] Based on these observations of spinal cats, a number of research teams around the world began testing similar treadmill stepping paradigms in humans.[18,19] Locomotor recovery with stepping practice on a treadmill is much greater than that ascribed to spontaneous recovery alone.[3,4] Typically, neurologically impaired subjects wear harnesses that support some of their bodyweight as therapists attempt to manually assist their legs through the stepping motion on a treadmill, (BWSTT), Figure 1 and 2.

Figure 1: Patient suspended with manual BWSTT

Figure 2: Video courtesy of University Hospital Balgrist, Zurich

Locomotor Gait Assisted Training refers to an intervention for retraining patients to walk after neurologic injury providing repetitive, intensive and task specific training that induces neuronal plasticity and subsequently cortical reorganization after brain and spinal cord damage. The neural mechanisms involved in bodyweight supported treadmill training (BWSTT) are not entirely understood but repetitive sensory stimulation appears to be critical. Motor recovery could result from formation of new neural pathways or modification of existing neural pathways.[14,23,24,31] It is likely that both contribute to some degree. The spinal cord and brain can each undergo considerable activity-dependent plasticity which is the nervous system's capacity for learning.

Neural plasticity refers to the natural ability of the neurons in the nervous system to generate and develop new connections aimed at repairing the neuronal damages. In the other word, they can learn new tasks. Based on this fact, locomotor training focuses on retraining the nervous system through simulating and repetition of walking gait, in order to regain their function and/or enhance their existing potentials. By repetitively stimulating the muscles and nerves in the lower body Lokomat Gait Assisted Training works to awaken dormant neural pathways controlling standing, stepping and balance.

The goals of locomotor training are to capitalize on the intrinsic mechanisms of the CNS that respond to sensory input associated with walking to generate a stepping response and on the ability of the CNS to learn through intensive, task-specific repetition and practice.[3,4] Researchers successfully used this strategy to train cats with complete midthoracic spinal cord transections to hind-limb step. Manual assistance to load the hind limbs and approximate the kinematics of stepping was used along with a sling linked to an overhead support for partial weight support and a treadmill to provide a controlled, repetitive training environment.[59,54] This training facilitated the sensory experience of walking and, with repetition, generated the motor response of stepping. Task specific training such as gait assisted walking enables repair and reorganization of processes in the central nervous system. In order to walk or regain functional capacity the injured patient must ‘re-learn to walk’.[80]

Experiments conducted on spinalized cats demonstrated that treadmill walk was possible suggesting evidence of a central gait pattern generator.[3,4,16,75,76,77,78,79] Therefore central nervous system lesions produce different symptoms: paresis, somatosensory deficits which induce inactivity and loss of function. This inability to realize a movement combined with the neuroplasticity of the central nervous system may induce a secondary functional incapacity called the “learning non use”.[45]

Growing number of incomplete SCI cases indicates an increasing need for treatment modalities, like Body Weight-Supported Treadmill Training that aim at maximizing and enhancing the existing potentials of these patients. A single-blind, randomized, multi-centre trial has shown that many patients with recent, incomplete SCI achieve independent walking when trained to step/stand, either using conventional devices or using body-weight-supported treadmill training.[85,18] People with chronic, incomplete SCI also benefit from treadmill or overground locomotor training: for example, improvements are seen in overground walking speed.[29] The most extensive study published to date found that 80% of wheelchair bound patients with chronic incomplete spinal cord injury gained functional walking ability after functional training.[75,78]

The BWSTT produces a constraint-induced movement therapy of a specific task - the gait training. The alternance of stance phase and swing phase generate afferent inputs which stimulate the spinal gait generator inducing a motor reorganization and acquisition of forgotten skills.[45]

Over the past decades, extensive research studies have assessed and evaluated the use and benefits of body weight-supported locomotor training. [3,4,5,9, 29,37,76, 77,78,81] These studies have revealed that BWSTT can effectively improve walking parameters such as speed,[5,6,29,15,16] limb coordination,[29] distance,[3,4,75] and level of independence.[37,5,6,75,76] It has also been shown that BWSTT in incomplete SCI patients can also lead some positive neurological alterations namely stepping ability,[4,5] corticospinal tract function,[72] and increased electromyography activity.[81,82,83,84] Manually assisted treadmill training has been used for more than 10-years as a regular training for patients with spinal cord injury and stroke.[3,4] Unfortunately BWSTT has not found prominence in Australian hospitals or private rehabilitation clinics.

More specifically for stroke hemiparetic patients BWSTT has been shown to improve balance,[33,34,35,36,73,74] lower limb motor recovery,[34,35,36,73,74] walking speed,[33,34,35,73,74,51] endurance,[71] and other important gait characteristics such as symmetry, stride length and

double stance time,[71] Other studies indicate positive therapeutic effects with other pathologies such as multiple sclerosis, Parkinson's disease and traumatic brain injury (TBI),[62,84,56] Huseman et al[42] reports significant improvement with stroke individuals in functional ambulation after 4-weeks Lokomat Gait Training.

Along with all the evidences showing the beneficial outcomes of BWSTT for incomplete SCI, there are a number of studies revealing that regaining some locomotor activities is also possible in the individuals with complete spinal cord injury.[3,415,16,18,75,76,77,78,79] The latter evidences have their roots back in numerous experimental studies on spinalized animals, such as cats.[75,77,4,15,16,18,23]

A secondary goal of Lokomat Gait Training is assisting in cardiovascular and metabolic exercise. A large number of patients with SCI could potentially benefit from aerobic exercise.[46] Wirz et al.[81,82,83,84] examined individuals who were more than 2 years postmotor incomplete. While aerobic exercise only slightly influenced balance and gait kinematics, the investigators found significant improvements in overground walking speed and endurance. Similar improvements in overground walking speed, endurance, and isolated muscle strength were observed in a study with several patients with acute SCI.[40,41]

In a separate study with eight individuals with TBI, a temporary digression was observed in overground walking speed and endurance performance during the initial days of Lokomat Gait Training.[55] By the end of training, however, significant improvements in overground gait speed and endurance, combined with improvements in spasticity and muscle strength scores, were observed.

A single-case or ABA design study with 16 stroke patients of different etiologies revealed greatly improved function, muscle strength, and walking endurance.[66] In both treatment groups, Lokomat Gait Training was superior to training with conventional physiotherapy. After training, patients walked more symmetrically with improved ankle dorsiflexion during the swing phase, demonstrated a stable stance phase with reduced spasticity, and developed adequate equilibrium reactions.[66]

What are the limits of Lokomat Gait Training? Wernig et al [76,77,78,79] reports patients with spinal cord injuries who have been wheelchair bound for many years are still potentially able to ambulate. Improving a patient to the point that he/she no longer needs a wheelchair to move would definitely lead to reducing the yearly costs of his/her neurological disease as well as the financial burden of wheelchair-associated complications such as; pressure ulcers, circulatory disorders, osteoporosis and attendant care. Lokomat Gait Training also records improved cardiovascular performance and reductions in spasticity, bone loss and bladder/bowel complications.[60, 18, 19, 80]

The Lokomat has been suggested to be predestined for patients with complex neurologic disability who are too weak to walk overground without external support and thus require the assistance of several therapists to perform body-weight- supported treadmill training.[56,57] Our experience (HyperMED NeuroRecovery) is that Lokomat Gait Training is highly adaptable for all patients with disability. Lokomat Gait Training can provide numerous accurate repetitions necessary to restore activity especially walking function with neurologic patients. Lokomat Gait Training kinetic settings can be varied and specifically adjusted throughout the training session intensifying functional outcomes. Isambert et al. reports patients with incomplete spinal lesions and with stroke undertaking Lokomat Gait Training have measurable functional changes; reflex stiffness and spasticity are significantly reduced; range of motion, peak velocity and acceleration of voluntary movements are increased with patients with incomplete spinal lesions and stroke. Therefore the walking ability improves as well as functional independence.

Additionally, it has been revealed that Lokomat Gait Training can lead to functional improvements in patients with different neurological diseases such as; Multiple Sclerosis,[52] Chronic Stroke,[26] Parkinson's Diseases,[30] Cerebral Palsy (CP),[63] as well as the other various types of idiopathic and secondary muscular dystrophies and neurological disorders in adult and children.[63,71]

Moreover, a number of research studies have shown that Lokomat Gait Training can not only improve the gait in neurological patients but also positively affect cardiovascular[17,61] and general health[61, 80] regulations. These neurological and physical improvements can remain between 6 months to 6.5 years post-BWSTT.[37,82,79] For this reason, to keep a level of maintenance treadmill training after the initial period of intense training is highly recommended.

Cerebral palsy is another complex disorder that also benefits from Lokomat Gait Training. Cerebral Palsy is an occurrence in which the nerves and muscles of the body function improperly; damage to the brain causes it to transmit incorrect electrical impulses to the muscles including both too many and too few signals. Without the correct cohesive electrical impulses to balance the opposing muscles of a joint, normal everyday tasks that most of us take for granted become very difficult to learn and perform. As robotic assisted exoskeletons become more advanced and practical, their applications have a lot of room for growth. Cerebral Palsy is one portion of the medical field that can benefit from the development of exoskeletons and in particular Pediatric Lokomat.

"The Economic Impact of Cerebral Palsy in Australia in 2007" gives us another example of this financial burden. This is an access economic report commissioned by Cerebral Palsy Australia, which estimated that, "in 2007, the financial cost of Cerebral Palsy (CP) in Australia was $1.47 billion or 0.14%of GDP. When the value of lost wellbeing (disability and premature death) was added, the cost raised a further $2.4 billion." 27 In this report, it has also been mentioned that, "33,797 Australian had CP in 2007. At an annual financial cost of $43,431 per person, the cost to the individual is estimated at 36.7% of the total or $306 per week. The Federal Government shares the bulk of the financial burden, bearing approximately 32.8% of the financial cost of the condition." [1]

Figure 3: HyperMED cerebral palsy patients on Pediatric Lokomat [43]

The Pediatric Lokomat (Figure 3) has been clinically deployed in our rehabilitation centre (HyperMED NeuroRecovery) since December 2006. Pediatric Lokomat offers opportunity to practice a most physiological gait pattern in a high intensity and frequency for children with gait impairment due to spinal or cerebral motor disorder including cerebral palsy. With this new tool, not only longer distances and therefore "higher dosages" of gait therapy, but also various and higher speeds can be trained, which is not possible to this extent with conventional physiotherapeutic methods. The Pediatric Lokomat raises many new topics of research about the effectiveness, dosage and age related application of this new therapy.

It is common practice in physical therapy to move a patient's limbs and joints through natural motion in order to improve function. Gait ability is a complex motor activation pattern organized hierarchically with the upper most level (initiation of the movement) mediated through the primary cortex and the lowest levels (organization and execution of the movement) mediated through the spinal motor neurons. There is evidence that innate pattern generators in the spine produce newborn stepping. During the first year of a child's development there is a transformation of this innate ability towards a normal plantigrade stepping through corticospinal tract development.[45] This process of learning is dysfunctional in children with cerebral palsy and then reinforced over time.[8]

The deficit induced by a central nervous system lesion depends on which group of cells is damaged: lesions of the upper motor neuron let some muscle contractions even with an altered highest cortical control. Lesions of the lower motor neuron result in flaccid paresis without

the ability to recover some movements. Therefore central nervous system lesions produce different symptoms: paresis, somatosensory deficits which induce inactivity and loss of function. This inability to realize a movement combined with the neuroplasticity of the central nervous system may induce a secondary functional incapacity called the "learning non use".[45] Functional incapacity is challenging for the child, parents and therapist. Acquired deformity results in a cascade effect of adaptation and dysfunction notwithstanding psychological effects.

Children with cerebral palsy have an acquired dysfunction which their central nervous system function deems normal. This is evident when CP children undertake an intensive Lokomat Gait Training protocol. Many of these children demonstrate a 'normal gait' whilst on the Lokomat which raises question of acquired neural pathways and motor function wrongly developed and reinforced over time. When these same children come off the Lokomat they immediately return back to the acquired gait. Intensity and repetition enables the CP child to generate a new functionality which resembles a 'normal gait'. It is a frequent finding to observe the bewilderment of both parents and CP child when the child sees themselves 'walking normal' on the Lokomat. Visualization whilst on the Lokomat is an important paradigm shift for not only the CP child and parent but also the therapist.

Winstein et al[81] reports task specific training such as Lokomat Gait Assisted Walking enables repair and reorganization of innate processes in the central nervous system. In order to walk or regain functional capacity the injured patient must re-learn to walk. Re-organization of processes refers to the development of the brain to find alternate pathways sending improved electrical signals. It is possible for the brain to transfer function responsibility to another part of the brain.[8] It has also been demonstrated that strength training in children with CP can increase strength as well as result in higher gait velocity.[12] Similar to strength training, treadmill training with partial body weight support, as discussed before, can improve walking speed and endurance of children with CP who can already walk.[20] Furthermore, it has been found that, in some cases, treadmill training with partial body weight support can achieve completely independent mobility for previously non-ambulatory children with CP.[67]

All the above mentioned improvements would lead to positively changing the quality of life of the affected individuals,[37] boost up their physical capacity,[9] their confidence and increase the valuable time they spent in their community.[5,80]

What the advantages of using Robotically Assisted Gait Training (Lokomat) compared to manual bodyweight supported treadmill training (BWSTT)?

Because manual assisted bodyweight supported treadmill training has high therapist labor requirements, research groups around the world have developed a host of robotic devices to assist treadmill stepping.[65,33,34,35] In manual BWSTT, at least three to four specially trained therapists are required to move the patient's legs and body (Figure 1). The purpose of these robotic machines is to replace therapist manual assistance, increasing the amount of stepping practice while decreasing therapist effort.

Manually assisted treadmill training (BWSTT) has several major limitations. The training is labor-intensive and biomechanically challenging to the active therapist; therefore, training duration is usually limited by personnel shortages and therapist, not patient fatigue. Furthermore, therapists often experience back pain because the training is performed in an ergonomically unfavorable seating posture. Consequently, training sessions are shorter than may be required for an optimal therapeutic outcome. The most compelling argument for Lokomat is that manually assisted treadmill training lacks accurate repeatability and objective measures of patient performance and progress. In contrast, the duration and number of sessions in Lokomat Gait Training can be accurately repeated and increased while reducing the number of therapists required for each patient. Indeed, one therapist may be able to train two or more patients at a time in the future.

The Lokomat®, developed by Hocoma[39] (Figure 4, 5), consists of a robotic lower limb interface that attaches to a treadmill frame and body weight support system.[10] The patient's legs are strapped into an adjustable aluminium frame that provides powered assistance at the hip and knee while the patient steps on a treadmill. The Lokomat hip and knee joints are actuated by linear drives, which are integrated in an exoskeletal structure. A rubber foot lifter induces passive ankle dorsiflexion during the swing phase. The patient's legs are moved with highly repeatable predefined hip- and knee-joint trajectories on the basis of a position-control strategy. Hip- and knee-joint torques are determined from force sensors integrated inside the Lokomat.[47,48]

A single therapist can monitor the Lokomat system and adjust assistance as necessary. The Lokomat has been shown to be effective in improving walking ability in individuals with incomplete spinal cord injury.[40,41,83] The Lokomat robot is fully controlled and programmed by a computer system. This computer can generates and coordinate almost all patterns of walking gait with a very high accuracy in both legs symmetrically, or on just one leg, asymmetrically. The partial body weight support allows patients to stand even with very weak muscles.

Treadmill speed and guidance assistance provided to the patient are also adaptable. Additionally, by reducing the "Guidance Force (GF)" on Lokomat we can allow the patient to move more voluntarily and freely. With a lowered guidance force (approximately below 60%) the patient can (and has to) walk more actively. As a result, this also allows the trainer to manually correct the movements of the patient's leg, any time as required. In the other word, trainer can change the setting from absolute to partially robotically-assisted training. From the above-mentioned facts we can conclude that robotically-assisted BWSTT (Lokomat) is superior providing more accurate control and parameters easily recreated when compared with manual BWSTT.

Lokomat has great advantage providing intensive task specific repetitive training that induces neuronal plasticity and subsequently cortical reorganization after brain and spinal cord damage. Patients with high level spasticity causing compensatory gait dysfunction are better suited on the Lokomat than manual BWSTT. Lokomat parameters can be initially set at very low and controlled setting providing a safe environment for the patient to develop confidence and allow functional reorganization through repetition and patterning. These parameters can then be built on and individually tailored to the specific requirements and functional responses of the individual patient. Lokomat provides task specific accuracy and repetition stimulating innate central pattern reflexes and higher cortical function.

Additionally, several built-in sensors constantly transfer electrical messages to the computer. The computer translates these messages into specific Biofeedback diagrams, shown on the two monitors (One viewed by the trainer and the other by the patient), to assist the technician to select the best training options for each individual.

Another main advantage of Lokomat Gait Training is that instead of having three or four specialized therapist involved in the treatment, only one trained technician can execute the entire training. This characteristic makes this modality highly cost effective. Based on the results of Morrison et al, [57] one major factor causing the difference in the total costs of different BWSTT modalities is directly related to the number of required staff. They realized that all other direct and indirect expenses are equal, in all BWSTT modalities. Derived from these results, robotically-assisted BWSTT (Lokomat) which only requires one trained technician can reduce the total cost of the treatment.

Figure 4: HyperMED Spinal Cord Injured patient on Lokomat[43]

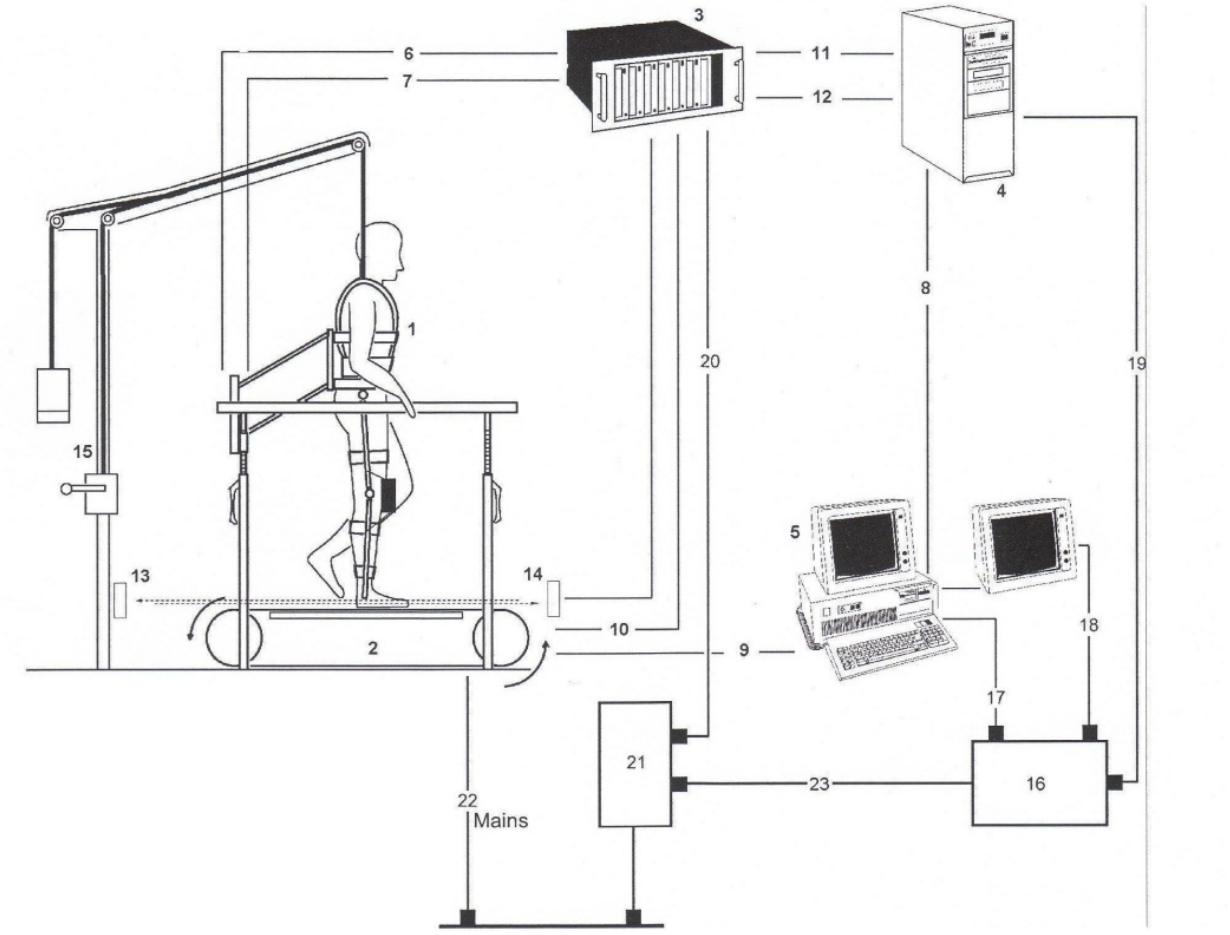

Figure 5: Lokomat courtesy Hocoma Inc[39]

System Componenets		Description
1.	Lokomat	Driven orthosis guiding the patients legs
2.	Treadmill	Electrically driven with parallel bars
3.	Lokopower	Power supply for Lokomat drives
4.	Lokomaster PC	PC with real time operating system and control program control and monitor the Lokomat
5.	Lokocontrol PC	PC with user interface Lokocontrol to control Lokomat system; Second monitor for the Biofeedback display
6.	Motor Cable	Power supply for the motors
7.	Sensor cable	Signal cable to measure the angle of the joints
8.	Control cable Lokomaster	Transmits control commands Lokocontrol PC-Lokomaster PC
9.	Control cable treadmill	Transmits control commands Lokocontrol PC-Treadmill
10.	Emergency stop cable	Integrates treadmill and the Lokomat in emergency stop loop
11.	A/D cable	Transmits sensor signals to control the Lokomat
12.	D/A cable	Transmits control signals to control the Lokomat
13.	Light curtain	Detects a misstep of the patient
14.	Light curtain cable	Transmits the light curtain signals
15.	Load alleviation	Weight support for the patient
16.	Separation transformer and Lokomaster PC	Transformer reducing the leakage current of non-medical equipment Lokocontrol PC, monitor,
17.	Mains cable	Power supply Lokocontrol PC

18.	Mains cable 2nd monitor	Power supply 2nd Biofeedback monitor
19.	Mains cable Lokomaster	Power supply Lokomaster PC
20.	Mains cable Lokopower	Power supply Lokopower
21.	Multiple socket outlet	Mains distribution
22.	Mains cable treadmill	Power supply treadmill

Conclusion

The incidence of brain and spinal cord disability has risen over recent years however individuals are living longer but with disability.[69] Lokomat systems enables longer and individually adapted training sessions, offering better chances for rehabilitation at lower cost compared to existing methods. A special focus is on optimised rehabilitation. Patients with spinal cord or brain injuries, orthopaedic lesions or age-related disorders very often need extensive rehabilitation therapies to improve their sensor-motor abilities in daily life.[10] In rehabilitation, the scientific basis for the applied treatments is often absent requiring proof of efficacy of a certain therapy. More and more innovative technologies are becoming available, which can precisely record the duration of the clinical course of recovery and reduce the strain on therapists, so that pioneering treatment options are developed. Lokomat Gait Training is one of these pioneering therapy options.[27]

HyperMED NeuroRecovery Centre provides intensive activity based rehabilitation programs with unique protocols incorporating Lokomat (Robotic Gait Assisted Walking), Hyperbaric Oxygenation, Median Nerve Stimulation, Neuro-acupuncture, Whole Body Vibration and other assertive therapies aimed at functional improvements of the patients with different sorts of neurological diseases and post operative events.

The HyperMED NeuroRecovery Centre has been the first and currently is the only centre in Australia, which has and uses the Robotically Assisted Lokomat; this lack of availability has meant that most patients attending HyperMED NeuroRecovery attend from interstate and many from overseas for this specific therapy combination.

HyperMED NeuroRecovery is a private therapeutic centre, which is totally funded by the patient and sponsored private sector. Patients attend in a private pay capacity; patients do not receive Government funding or funding under Third Party Insurance including Transport Accident Commission or WorkCover. Self-funded rehabilitation facilities such as HyperMED NeuroRecovery Centre, by using the Lokomat can play an important role in reducing the financial burden of neurological diseases on the government and communities' shoulders.

HyperMED NeuroRecovery provides financial subsidy for all patients attending. This economic burden has been tackled by the directors in the interest of providing modalities including Lokomat Gait Training for patients with neurologic disorders.

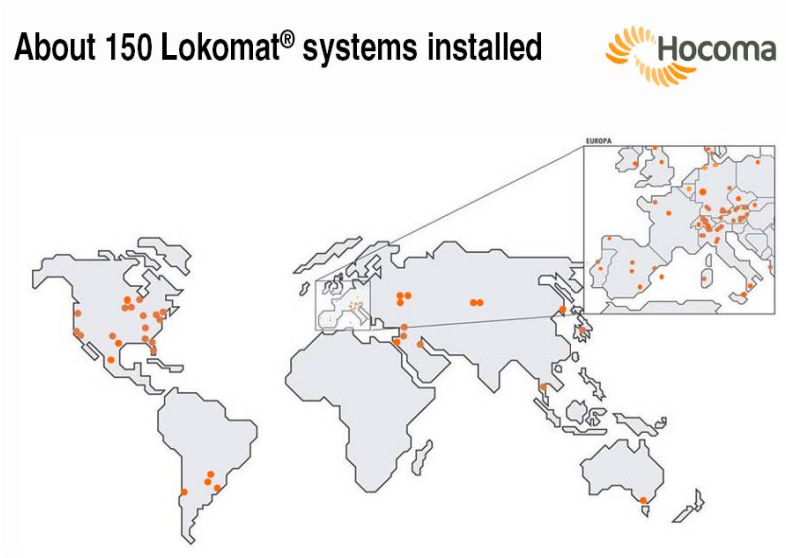

Figure 6: Lokomat systems installed world-wide [39]

References:

1. "The Economic Impact of Cerebral Palsy in Australia in 2007". An Access Economic Report commissioned by Cerebral Palsy Australia. 2007. 79: 119-125 Archives of Physical Medicine & Rehabilitation, 81: 301-6
2. Barbeau H, Rosiignol S. Spinal cord injury: enhancement of locomotor recovery. Curr Opin Neurol. 1994;7:517-524.
3. Barbeau H. Locomotor training in neurorehabilitation: emerging rehabilitation concepts. *Neurorehabil Neural Repair*. 2003;17:3-11.
4. Barbeau, H; Rossignol, S. Recovery of locomotion after chronic spinalization in the adult cat. Brain Res. 1987;412(1):84–95.
5. Behrman A, Harkema S. Locomotor training after human spinal cord injury: a series of case studies. Phys Ther. 2000;80:688-700.
6. Behrman A, Lawless-Dixon A, Davis S, et al. Locomotor training progression and outcomes after incomplete spinal cord injury. Phys Ther. 2005;85:1356-1371.
7. Bouyer, L. J. Animal models for studying potential training strategies in persons with spinal cord injury. *J. Neurol. Phys. Ther.* 29, 117–125 (2005).
8. Burnett B. Considerations for the use of an Exoskeleton for Extremity Control and Assistance when learning to Walk with Cerberal Palsy p12.
9. Carvalho Dc, de Cassia Zanchetta M, Sereni JM, et al. Metabolic and cardiorespiratory responses of tetraplegic subjects during treadmill walking using neuromuscular electrical stimulation and partial body weight support. Spinal Cord. 2005;43:400-405.
10. Colombo, G; Joerg, M; Schreier, R; Dietz, V. Treadmill training of paraplegic patients using a robotic orthosis. J Rehab Res Dev. 2000;37(6):693–700.
11. Curt, A. , Schwab, M. E. & Dietz, V. Providing the clinical basis for new interventional therapies: refined diagnosis and assessment of recovery after spinal cord injury. *Spinal Cord* **42**, 1–6 (2004).
12. Damiano, D.L., and Abel, M.F. (1998) 'Functional Outcomes of Strength Training in Spastic Cerebral Palsy', *Archives of Physical Medicine & Rehabilitation*,
13. Danielsson A, Sunnerhagen KS. Oxygen consumption during treadmill walking with and without body weight support in patients with hemiparesis after stroke and in healthy subjects. Arch Phys and Rehabil. 2000;81(7):953-957.
14. de Leon, RD; Roy, RR; Edgerton, VR. Is the recovery of stepping following spinal cord injury mediated by modifying existing neural pathways or by generating new pathways? A perspective. *Phys Ther.* 2001;81(12):1904–1911.
15. Dietz V, Colombo G, Jensen L, Baumgartner L. Locomotor capacity of spinal cord in paraplegia patients. Ann Neurol. 1995;37:574-582.
16. Dietz V, Colombo G, Jensen L. Locomotor activity in spinal man. Lancet. 1994;344:1260-1263.
17. Ditor DS, MacDonald MS, Kamath M, Bugaresti J, Adams M, McCartney N, Hicks AL. The effects of Body-Weight Supported Treadmill Training on Cardiovascular regulation in individuals with motor-complete SCI. Spinal Cord. 2005;43(11):664-675.
18. Dobkin BH, Harkema S, Requejo P, Edgerton R. Modulation of locomotor-like EMG activity in subjects with complete and incomplete spinal cord injury. J Neuro Rehab. 1995;9:183-190.
19. Dobkin, B. *et al*. Weight-supported treadmill vs over-ground training for walking after acute incomplete SCI. *Neurology* **66**, 484–493 (2006).
20. Dodd, K.J., (2007) 'Partial Body-Weight-Supported Treadmill Training can Improve Walking in Children with Cerebral Palsy: A Clinical Controlled Trial', *Developmental Medicine & Child Neurology*, 49: 101-105
21. Dodd, K.J., Taylor, N.F., and Graham, H.K. (2003) 'A Randomized Clinical Trial of Strength Training in Young People with Cerebral Palsy', *Developmental*
22. Edgerton, V. R. , Kim, S. J. , Ichiyama, R. M. , Gerasimenko, Y. P. & Roy, R. R. Rehabilitative therapies after spinal cord injury. *J. Neurotrauma* **23**, 560–570 (2006).
23. Edgerton, V. R. , Tillakaratne, N. J. , Bigbee, A. J. , de Leon, R. D. & Roy, R. R. Plasticity of the spinal neural circuitry after injury. *Annu. Rev. Neurosci.* **27**, 145–167 (2004).
24. Edgerton, VR; Roy, RR; de Leon, RD. Neural Darwinism in the mammalian spinal cord. In: Patterson MM, Grau JW. , editors. *Spinal Cord Plasticity: Alterations in Reflex Function.* Kluwer Academic Publishers; Boston: 2001. pp. 185–206.
25. Engesser-Cesar, C. , Anderson, A. J. , Basso, D. M. , Edgerton, V. R. & Cotman, C. W. Voluntary wheel running improves recovery from a moderate spinal cord injury. *J. Neurotrauma* 22, 157–171 (2005).

26. Enhanced gait-related improvements after therapist-versus robotic-assisted locomotor training in subjects with chronic stroke. A randomized controlled study.
27. Ferris D, Sawicki G, Domingo A, Powered lower limb orthoses for gait rehabilitation Spinal Cord Inj Rehabil. 2005; 11(2): 34–49.
28. Field-Fote EC, Tepavac D. Improved intralimb coordination in people with incomplete spinal cord injury following training with body weight support and electrical stimulation. Phys Ther. 2002;82:707-715.
29. Field-Fote, E. C. , Lindley, S. D. & Sherman, A. L. Locomotor training approaches for individuals with spinal cord injury: a preliminary report of walking-related outcomes. *J. Neurol. Phys. Ther.* **29**, 127–137 (2005).
30. Fisher BB, Wu AD, Salem GJ, Song J, Lin CH, Yip J, Cen S, Gordon J, Jakowee M, Petzinger G. The effect of exercise in improving motor performance and corticomotor excitability in people with early Parkinson's Disease. Arch Phys Med Rehabil. 2008;89(7):1221-1229.
31. Grasso, R; Ivanenko, YP; Zago, M, et al. Distributed plasticity of locomotor pattern generators in spinal cord injured patients. *Brain.* 2004;127(5):1019–1034.
32. Henry, FM. Specificity vs. generality in learning motor skill. In: Brown RC, Kenyon GS. , editors. Classical Studies on Physical Activity. Prentice-Hall; Englewood Cliffs, N.J.: 1968. pp. 331–340.
33. Hesse S, Bertelt C, Jahnke MT, Schaffrin A, Baake P, Malezic M, Mauritz KH. Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. Stroke. 1995;26(6): 976–81.
34. Hesse S, Bertelt C, Schaffrin A, Malezic M, Mauritz KH. Restoration of gait in nonambulatory hemiparetic patients by treadmill training with partial body-weight support. Arch Phys Med Rehabil. 1994;75(10):1087–93.
35. Hesse S, Schmidt H, Werner C, Bardeleben A. Upper and lower extremity robotic devices for rehabilitation and for studying motor control. Curr Opin Neurol 2003;16:705-10.
36. Hesse, S; Schmidt, H; Werner, C; Bardeleben, A. Upper and lower extremity robotic devices for rehabilitation and for studying motor control. Curr Opin Neurol. 2003;16(6):705–710.
37. Hicks AL, Adams MM, Martin GK, et al. Long-term body-weight supported treadmill training and subsequent follow-up in persons with chronic SCI: effects on functional walking ability and measures of subjective well-being. Spinal Cord. 2005;43:291-298.
38. Hidler J. Robotic-assessment of walking in individuals with gait disorders. Conf Proc IEEE Eng Med Biol Soc. 2004;7:4829-4831.
39. Hocoma web site http://www.hocoma.ch providing back ground material including: Robotic-assisted locomotor training in gait rehabilitation of children http://www.hocoma.ch/index.php?lang=de&page=/pages/interestgroups/pediatric_de.html
40. Hornby TG , Zemon DH, Campbell D. Robotic-assisted, body-weight-supported treadmill training in individuals following motor incomplete spinal cord injury. Phys Ther. 2005;85(1):52–66.
41. Hornby, TG; Zemon, DH; Campbell, D. Robotic-assisted, body-weight-supported treadmill training in individuals following motor incomplete spinal cord injury. Phys Ther. 2005;85(1):52–66. 38.
42. Husemann B, Muller F, Krewer C, Heller S, Koenig E Effects of Locomotion Training with Assistance of a Robot Driven Gait Orthosis in Hemiparetic Patients After Stroke 'A Randomized Controlled Piolet Study', Stroke. 2007;38:349.
43. HyperMED NeuroRecovery website: www.hypermed.com.au
44. Ichiyama, R. M. , Gerasimenko, Y. P. , Zhong, H. , Roy, R. R. & Edgerton, V. R. Hindlimb stepping movements in complete spinal rats induced by epidural spinal cord stimulation. *Neurosci. Lett.* 383, 339–344 (2005).
45. Isambert J.L., Bébin Y., Injeyan S., Le Doze S., Hugeron C., Lecamp G. Centre de Rééducation Fonctionnelle "Le Normandy", Granville, France Robotic Assisted Body Weight Supported Treadmill Training (Lokomat) of Neurologic Impaired Patients: Preliminary Results 2007.
46. Jacobs PL, Nash MS. Exercise recommendations for individuals with spinal cord injury. Sports Med. 2004;34(11): 727–51.
47. Jezernik S, Colombo G, Morari M. Automatic gait-pattern adaptation algorithms for rehabilitation with a 4-DOF robotic orthosis. IEEE Trans Rob Autom. 2004;20(3):574–82.
48. Jezernik S, Scharer R, Colombo G , Morari M. Adaptive robotic rehabilitation of locomotion: A clinical study in spinally injured individuals. Spinal Cord. 2003;41(12): 657–66.
49. Kaelin-Lang, A; Sawaki, L; Cohen, LG. Role of voluntary drive in encoding an elementary motor memory. J Neurophysiol. 2005;93(2):1099–1103.

50. Lam T, Eng J, Wolfe D, Hsieh J, Whittaker M. A Systemic Review of the Efficacy of Gait Rehabilitation Strategies for Spinal Cord Injury. Topics in Spinal Cord Injury Rehabilitation. Vol13 Num1 Summer 2007.
51. Laufer Y, Dickstein R, Chefez Y, Marcovitz E. The effect of treadmill training on the ambulation of stroke survivors in the early stages of rehabilitation: A randomized study. J Rehabil Res Dev. 2001;38(1):69–78.
52. Lo AC, Triche EW. Improving gait in Multiple Sclerosis using Robot-assisted, body weight supported treadmill training. Neurorehabil Neural Repair. 2008;22(6):661-671.
53. Lotze, M; Braun, C; Birbaumer, N; Anders, S; Cohen, LG. Motor learning elicited by voluntary drive. Brain. 2003;126:866–872.
54. Lovely RG, Gregor RJ, Roy RR, Edgerton VR. Effects of training on the recovery of full-weight-bearing stepping in the adult spinal cat. *Exp Neurol*. 1986;92:421-435.
55. Mayr A, Luenenburger L, Quirinbach E, Matzak KH, Froehlich K, Kofler M, Saltuari L. First experiences with the Lokomat in patients with severe traumatic brain injury. Brain Inj. 2003;17 Suppl 1:46–47.
56. Mayr A, Quirbach E, Kofler M, Saltuari L. First experience with the "Lokomat" gait orthosis in post-acute brain-injured patients [abstract]. Eur J Neurol. 2002;9(Suppl 2):22. *Medicine & Child Neurology*, 45: 652-657
57. Morrison SA, Backus D. Locomotor Training: Is Translating Evidence Into Practice Financially Feasible? JNPT. 2007;31:50-54.
58. Moseley AM, Stark A, Cameron ID, Pollock A. Treadmill training and body weight support for walking after stroke. *Cochrane Database Syst Rev*. 2003;(3):CD002840.
59. Nash, M. S. Exercise as a health-promoting activity following spinal cord injury. *J. Neurol. Phys. Ther.* **29**, 87–103, 106 (2005).
60. Phillips SM, Stewart BC, Mahoney DJ, Hicks AL, McCartney N, Tang JE, Wilkinson SB, Armstrong D, Tarnopolsky MA. Body-weight support treadmill training improves blood glucose regulation in person with incomplete spinal cord injury. J Appl Physiol. 2004;97(2):716-724.
61. Prokop T, Berger W. Influence of optic flow on locomotion in normal subjects and patients with Parkinson's disease [abstract]. Electroencephalogr Clin Neurophsiol. 1996; 99:370.
62. Provost B, Dieruf K, Burtner PA, Phillips JP, Bernitsky-Beddingfield A, Sullivan KJ, Bowen CA, Toser L. Endurance and gait in children with cerebral palsy after intensive body weight-supported treadmill training. Pediatr Phys Ther. 2007;19(1):2-10.
63. Raineteau, O. & Schwab, M. E. Plasticity of motor systems after incomplete spinal cord injury. *Nature Rev. Neurosci.* 2, 263–273 (2001).
64. Reinkensmeyer, DJ; Emken, JL; Cramer, SC. Robotics, motor learning, and neurologic recovery. Ann Rev Biomed Eng. 2004;6:497–525. 35.
65. Saltuari L. Efficiency of Lokomat training in stroke patients [abstract]. 3rd Joint Congress of Swiss Society of Neurore-habilitation, Austrian Society of Neurorehabilitation, Ger-man Society for Neurological Rehabilitation and 1st Regional Meeting of World Federation for NeuroRehabili-tation in association with German Speaking Medical Soci-ety for Paraplegia in Neurol Rehab. 2004;10(4):169–78.
66. Schindl, M.R., Forstner, C., Kern, H., and Hesse, S. (2000) 'Treadmill Training With Partial Body Weight Support in Nonambulatory Patients with Cerebral Palsy',
67. Schmidt, RA; Lee, TD. Motor Control and Learning: A Behavioral Emphasis. 3rd. Human Kinetics; Champaign, IL: 1999.
68. Schouenborg, J. Learning in sensorimotor circuits. *I.* 2004;14(6):693–697.
69. Spinal Cord Injury: Facts & Figures at a Glance. Birmingham, AL: University of Alabama, National Spinal Cord Injury Statistical Centre, 2005.
70. Suteerawattananon M, MacNeill B, Protos EJ. Supported treadmill training for gait and balance in a patient with progressive supranuclear palsy. Phys Ther. 2002;8215:485-495.
71. Teixeira da Cunha Filho I, Lim PA, Qureshy H, Henson H, Monga T, Protas EJ. A comparison of regular rehabili-tation and regular rehabilitation with supported treadmill ambulation training for acute stroke subjects. J Rehabil Res Dev. 2001;38(2):245–55.
72. Tomas SL, Gorassini MA. Increase in corticospinal tract function by treadmill after incomplete spinal cord injury. J Neurophysiol. 2005;94:2844-2855.
73. Visintin M, Barbeau H, Korner-Bitensky N, Mayo NE. A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. Stroke. 1998;29(6):1122–28.

74. Visintin M, Barbeau H, Korner-Bitensky N, Mayo NE. A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. Stroke. 1998;29(6):1122–28.
75. Wernig A, Muller S, Nanassy A, et al. Laufband therapy based on “rules of spinal locomotion” is effective in spinal cord injured persons. Eur J Neurosci. 1995;7:823-829.
76. Wernig A, Muller S. Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries. Paraplegia. 1992;30:229-238.
77. Wernig A, Nanassy A, Muller S. Laufband (treadmill) therapy in incomplete paraplegia and tetraplegia. J Neurotrauma. 1999;16:719-726.
78. Wernig A, Nanassy A, Muller S. Maintenance of locomotor abilities following Laufband (treadmill) therapy in para and tetraplegic persons: follow-up studies. Spinal Cord. 1998;36:744-749.
79. Wernig, A. Long-term body-weight supported treadmill training and subsequent follow-up in persons with chronic SCI: effects on functional walking ability and measures of subjective well-being. *Spinal Cord* **43**, 291–298 (2005).
80. Winstein CJ (1991) Knowledge of Results and Motor Learning – Implications for Physical Therapy, Physical Therapy Vol. 71, No. 2, pp. 140(10).
81. Wirz M, Colombo G, Dietz V. Long term effects of locomotor training in spinal humans. J Neursurg Psychiatry. 2001;71:93-96.
82. Wirz M, Zemon DH, Rupp R, Scheel A, Colombo G , Dietz V, Hornby TG. Effectiveness of automated locomo-tor training in patients with chronic incomplete spinal cord injury: A multicenter trial. Arch Phys Med Rehabil. 2005;86(4):672–80.
83. Wirz M, Zemon DH, Rupp R, Scheel A, Colombo G , Dietz V, Hornby TG. Effectiveness of automated locomo-tor training in patients with chronic incomplete spinal cord injury: A multicenter trial. Arch Phys Med Rehabil. 2005;86(4):672–80.
84. Wirz, M; Zemon, DH; Rupp, R, et al. Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: A multicenter trial. Arch Phys Med Rehabil. 2005;86(4):672–680.
85. Wolpaw, J. R. Treadmill training after spinal cord injury: good but not better. *Neurology* **66**, 466–467 (2006).