THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by

Mary P. Galea

2007 Churchill Fellow

To investigate active rehabilitation programs for people with spinal cord injury.

Signed : Dated : 18th June 2008

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Introduction

There is mounting evidence that a comprehensive exercise program including stimulation of the paralysed limbs can promote neural recovery and good health, and reduce secondary complications such as pressure ulcers and fractures. Innovative "activity-based therapies" have been shown to restore neurological function and are based on principles of experimental psychology, exercise physiology and neuroscience. In Australia considerable effort is directed towards maximizing independence through compensatory strategies using the non-paralysed limbs, especially in people with clinically complete injuries. In part this has been the result of the prevailing paradigm that only limited recovery is possible following spinal cord injury. However, the therapy resources in Australian spinal rehabilitation units are also insufficient to provide comprehensive exercise programs beyond the initial period of rehabilitation for people with spinal cord injury.

Given the published reports that such programs might have substantial health benefits, I visited leading spinal injury clinical and research centres in the USA, Canada and Europe to investigate the content, delivery, and evidence for exercise programs for people with spinal cord injury.

Acknowledgements

I gratefully acknowledge the support of the Churchill Trust that enabled this trip, and the professional and personal development opportunity afforded by it. I am also indebted to all the clinicians and researchers I met for their generosity in making time to speak with me and sharing information, and for their hospitality. I greatly value the connections that I made and hope to take advantage of the opportunities to develop collaborative research with some of these individuals.

Executive Summary

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Fellowship objective: To investigate active rehabilitation programs for people with spinal cord injury.

Highlights and lessons for Australia

- Currently, exercise is the only known intervention that can have lasting effects on function after spinal cord injury, both in promoting neural recovery and in reducing secondary complications.
- A paradigm shift has occurred in the way spinal cord injury rehabilitation is delivered in leading centres in the USA, Canada and Europe. Best practice includes provision of a comprehensive exercise program that includes, but is not limited to, the use of functional electrical stimulation and body weight-supported treadmill training to stimulate the paralysed limbs and improve functional outcomes.
- Key research centres (ICORD, Miami Project, Kentucky Spinal Cord Injury Research Center) include clinical research in rehabilitation as a major research stream alongside research in the basic sciences. This broad, interdisciplinary approach facilitates translation of research outcomes into clinical practice.
- Dedicated government funding in the area of spinal cord injury facilitates collaborative research (e.g. Canadian SCI Translational Research Network; Model Systems in Spinal Cord Injury through NIDRR) to improve clinical outcomes.

Recommendations

- Ongoing comprehensive exercise programs for people with spinal cord injury should be provided to optimize their level of neural recovery and independence and to improve their general health.
- Australian Spinal Cord Injury Units should be adequately resourced to deliver such programs and to facilitate their continuation in the community after discharge. Inclusion of exercise specialists on the rehabilitation team should be encouraged.
- Dedicated Federal funding programs in the USA and Canada provide a paradigm for fostering clinically-based collaborative research, including establishment of a national database for spinal cord injury, and clinician exchange programs. The Australian and New Zealand Spinal Cord Injury Network (ANZSCIN) would be an appropriate vehicle for direction and management of these funds.
- Australian Universities should consider offering a specialized program in Rehabilitation Engineering to harness local innovations to develop and adapt new technology to meet the needs of people with spinal cord injury or other disabilities.

Program

Dates	Location	Contact
24-26 Oct	Carlsbad CA	Eric Harness Project Walk 2738 Loker Avenue Carlsbad, CA 92010
30 Oct-3 Nov	Los Angeles CA	Dr Reggie Edgerton Dept of Physiological Sciences University of California, Los Angeles 621 Charles E. Young Drive South Los Angeles, CA 90095-1761 Dr Bruce Dobkin Reed Neurological Research Institute University of California, Los Angeles Dr Carolee Winstein Motor Control Laboratory Dept Kinesiology and Physical Therapy University of Southern California Alcazar Street Los Angeles CA
3-6 Nov	Vancouver, Canada	Dr Chris McBride ICORD University of British Columbia 6270 University Blvd Vancouver, BC V6T 1Z4
6-11 Nov	Edmonton, Canada	Prof Arthur Prochazka, Div Neuroscience, 507 HMRC, University of Alberta, Edmonton, Alberta T6G 2S2, Glenrose Rehab Hospital 10230 – 111 Avenue, Edmonton, AB, T5G OB7
11-14 Nov	Toronto, Canada	Heather Flett Lyndhurst Centre Spinal Cord Injury Program 520 Sutherland Drive Toronto, Ontario M4G 3V9

14-19 Nov	Denver CO	Darrell Musick (PT), Ellen Severe (OT) Craig Hospital 3425 S. Clarkson St. Englewood, CO 80113
19-25 Nov	Miami FL	A/Prof Edelle Field-Fote The Miami Project to Cure Paralysis 1095 NW 14th Terrace, Miami, FL 33136
25-28 Nov	Atlanta GA	Dr Mike Jones Shepherd Center 2020 Peachtree Road, NW Atlanta, GA 30309-1465
28 Nov- 2 Dec	Louisville KY	Dr Susan Harkema, Kentucky Spinal Cord Injury Research Center University of Louisville 511 S. Floyd St. Louisville, KY 40292
2-5 Dec	Pittsburgh PA	Prof Peter Strick University of Pittsburgh Center for the Neural Basis of Cognition W1640 Biomedical Science Tower 200 Lothrop Street Pittsburgh, PA 15261
5-7 Dec	New York NY	Prof Kristjan Ragnarsson Mt Sinai Spinal Cord Injury Model System Department of Rehabilitation Medicine One Gustave L. Levy Place, New York, NY 10029
8 Dec	West Orange NJ	Dr Gail Forrest and Dr Sue Ann Sisto Kessler Spinal Cord Injury Research Center 1199 Pleasant Valley Way, West Orange, New Jersey
8-16 Dec	London UK	Prof Peter Ellaway Division of Neurosciences and Mental Health Imperial College London Tel: +44 (0)20 8846 7293 The London Spinal Injuries Unit Royal National Orthopaedic Hospital Brockley Hill Stanmore HA7 4LP

16-21 Dec	Switzerland	Prof Volker Dietz Neural Plasticity and Repair University Hospital Balgrist University of Zurich Winterthurer Str. 190 CH-8057 Zűrich Angela Frotzler Swiss Paraplegia Centre Postfach CH-6207 Nottwil
21-23 Dec		Return to Melbourne

Project Walk, Carlsbad, California

My host was Eric Harness, Director of Research, Certified SCI (Spinal Cord Injury) Recovery Specialist. My visit to Project Walk was compromised by the fires in the San Diego area at the time. The facility was closed for a few days because staff and clients were affected by the fires.

Program

The idea behind *Project Walk* emerged from the training of a person with spinal cord injury (SCI) by Ted Dardzinski, an exercise physiologist. The client achieved significant functional improvement. Ted gradually attracted other exercise physiologists like Eric, to work with him.

The Darzinski Method™ as reported on the *Project Walk* website provides the basis for treatment at this facility. There is no literature cited to support this Method.

- *Phase I (Reactivation)/Phase II (Development/Stabilization)*
  Goal: To stimulate the nervous system with load bearing and active recruitment to develop joint stabilization.
- *Phase III (Strength: Eccentric/Concentric Muscle Contractions)*
  Goal: To initiate muscle contractions through positional movement or stimulation.
- *Phase IV (Function & Coordination)*
  Goal: Control coordinated movement through all planes of movement and motion.
- *Phase V (Gait Training)*

An "in-house" exercise program is the preferred option. This is offered on a long-term basis, usually 3 times per week. For those who cannot afford this, a trial week is provided. For others, five treatment sessions are videotaped so that a carer or therapist can undertake the training program at home with their client. There is also a Train-the-Trainer program, a one-week intensive educational and training course that introduces exercise professionals to the methods used at *Project Walk*, including safety guidelines.

Project Walk sees 35 clients per week, each attending for 3-4 hours 3 times per week. The cost is $100 per hour, but the program is already subsidized to the extent of $15-$20 per session. An active fund-raising program is aimed at providing subsidies for SCI clients who cannot afford the treatment. Clients pay from their own pocket; however, negotiations are currently underway regarding Workman's Compensation covering the cost of treatment at *Project Walk*.

The treatments are individually prescribed by a qualified SCI Recovery Specialist and follow the principles of the Dardzinski Method™. Essentially, the clients undertake a circuit of activities ranging from working on a plinth or on a mat to standing and walking activities. A form of body weight supported treadmill training is available, as is

Functional electrical stimulation (FES) assisted-cycling. Two or three SCI Recovery Specialists might work together with one client for certain activities, e.g. supporting him in four-point kneeling. Weight-bearing activities are consistently encouraged.

Referrals

Initial referrals to the *Project Walk* were by word of mouth from SCI clients. Now some physiatrists are starting to refer clients to *Project Walk*, although neurologists with whom I spoke remain skeptical, largely because of the lack of evidence for this program. Most clients commence treatment many months after injury, however, some are now starting the program earlier.

Project Walk has several sites in the USA: Carlsbad CA, Portland OR, Boston (Spaulding) MA and there will be a site in San Francisco in the near future. Certified Project Walk facilities include *Push to Walk*, Bloomingdale NJ, and *Walk On*, Brisbane Australia.

There are also so-called 'rival' treatment centres set up by former SCI patients or former trainers from *Project Walk*. These include:
Beyond Therapy – Shepherd Center, Atlanta
Awakenings – Solana Beach, California
Next Steps – Chicago & Seattle

Discussions with staff and clients

When questioned about adverse events, Eric reported that there had been only a couple of instances of lower limb fractures during exercising. Now *Project Walk* requests bone scan information prior to accepting clients. There had also been a couple of cases of autonomic dysreflexia which were managed in the standard way (transport by ambulance to hospital). Most clients I spoke with had weaned themselves off anti-spasmodic medication before they started their program and reported that their spasticity was no worse off-medication. Some continued to take anti-spasmodics to reduce night spasms.

All of the clients I met during my visit were in the chronic stages of their injury (>6 months post-injury) except for an 18 year old with a C5-6 SCI whose injury was quite

recent. His family reported an improvement in his health and mood after just 3 weeks of treatment. Some of the clients I met had been attending *Project Walk* for 12 months or more; some had moved to the San Diego area from other states to be able to access the services of *Project Walk*. Universally, the clients I met reported dissatisfaction with standard rehabilitation, which they believed was focused heavily on learning compensatory strategies rather than on promoting their recovery. The level of outpatient rehabilitation provided was considered insufficient, ignored the affected limbs, and the attitude of the rehabilitation personnel "took away hope".

Project Walk, on the other hand, offered them the opportunity to undertake an exercise program that they believed would assist them. These clients reported improvement after commencing the *Project Walk* program, although to varying degrees. Some had progressed to the stage of walking, using a gutter frame or forearm crutches. Others reported substantial improvements in sitting balance. Some noted improvements in sensation. All reported better health, a sense of well-being and improvements in strength and function. They took inspiration from other clients receiving treatment. Many reported improvements in bowel function, mainly in terms of regularity and the sensation of when they needed to open their bowels. While their urinary function had not changed very much, and intermittent catheterization was still required, many clients reported better urinary sensations. Clients are informed by staff from the outset that progress is individual and each client has individual needs and goals. An example of the training journey of a person with SCI (N.B. not volunteered by *Project Walk*) is provided at the following website: http://www.darrentempleton.com/Training.html

Research

A formal research project was recently undertaken in which 21 subjects who had rehabilitation for 6 months at Project Walk were compared with 9 control subjects who had standard rehabilitation elsewhere. The project was done in collaboration with Dr Steven Cramer at University of California (UC) Irvine.

The study tested the hypothesis that intense exercise will improve motor system function more than the control (no prescribed exercise). The primary endpoint measurement was the ASIA scale. Secondary endpoints included assessing eccentric leg press force, sitting balance (using an accelerometer), TMS (transcranial magnetic stimulation) measurements, fMRI (Functional MRI) of brain activation and anatomical measurements of spinal cord diameter. The first group of assessments was performed twice at UC Irvine, in all patients: once at study baseline and a second time 6 months later. These assessments were (1) motor behavior; (2) human brain mapping with fMRI scanning while patients attempted to move the right foot at 0.25 Hz; and (3) transcranial magnetic stimulation over the leg motor area (MEP latency and magnitude)

The second group of assessments was performed every three weeks for patients in the exercise group. These assessments were leg strength, leg range of motion, and body sway, measured using devices that could relay information via a broadband modem. A paper had been submitted and was recently published (Harness et al. 2008).

Reference

Harness ET, Yozbatiran N, Cramer SC (2008) Effects of intense exercise in chronic spinal cord injury. *Spinal Cord* Jun 3. [Epub ahead of print].

Staff Training

A facility must have a license to be a certified Project Walk Facility. Training costs are $2500 per person for 4 weeks training at *Project Walk*. Certification entails a trainer coming to the facility every six months to update staff training.

Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles

The program for the visit was as follows:

Attendance at Dr Carolee Winstein's lab meeting

PhD student presentations by:

- Shailesh Kantak – rTMS to motor cortex after learning disrupts constant practice retention but not variable practice retention.
- Jeong Yoon Lee - A model of motor learning.

Meetings

- Jill Stewart, a PhD student undertaking research into the feasibility of using Virtual Reality to retrain upper extremity function (Stewart et al. 2006, 2007). The *Flock of Birds* system of electromagnetic markers is used to provide the location of the paretic hand in the virtual environment, and *PHANToM* devices to provide force feedback. Tasks involved reaching, pinch grasp, rotation and ball shooting. I was interested in Jill's view of the *PHANToM* devices as we have also tried to use them in a project currently being undertaken in collaboration with MUVES (Melbourne University Virtual Environments for Simulation) to develop a robotic device to assist people with severe upper limb impairment. Our view was that the *PHANToM* was not sufficiently reliable for our needs, and this was confirmed by Jill, as she had similar concerns. She has also recommended the Functional Test of the Hemiplegic Upper Extremity (Wilson et al. 1984) as an outcome measure, particularly for patients with low-level function.

- Dr James Gordon, Chair of the Division of Biokinesiology and Physical Therapy and an expert on motor control and motor learning.

- Dr Nicolas Schweighofer, whose expertise is in computational modeling of motor skill learning and motivation.

- Dr Nina Bradley, whose research is focused on motor development in the chick. Current research is investigating variation in chick development under different environmental conditions (24 hours light, 12 hours light - 12 hour dark, 24 hours dark). There is delayed hatching under the 24 hour dark condition resulting in apparently better motor control.

- Dr Christopher Powers who has shown that training of motor control of hip and knee musculature on landing results in reduction in injuries in female soccer players.

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designed to enhance recovery of skilled arm and hand movements after stroke. *Proceedings of the International Workshop on Virtual Reality*, pp.11-17.

Stewart JC, Yeh S-C, Jung Y, Yoon H, Whitford M, Chen S-Y, Li L, McLaughlin M, Rizzo A, Winstein CJ (2007) Intervention to enhance skilled arm and hand movements after stroke: A feasibility study using a new virtual reality system. *J NeuroEng Rehabil* 4:21.

Wilson DJ, Baker LL, Craddock JA (1984) Functional Test for the Hemiplegic Upper Extremity. *Am J Occ Ther* 38(3):159-164.

Department of Physiological Sciences, University of California Los Angeles

Background

The purpose of my visit was to meet with Dr Reggie Edgerton, a neuroscientist and engineer who is an expert in the investigation of neural networks in the lumbar spinal cord that control stepping and how they change with spinal cord injury and with training. He has shown that learning of complex motor tasks such as standing and stepping is task-specific. Moreover, he has shown that the lumbosacral spinal cord responds to perturbations applied to the lower shank during stance by modifying step timing and muscle activation patterns, while preserving the kinematics during swing phase and interlimb coordination (Timosyzk et al. 2002).

Issues discussed

Role of exercise following SCI

We discussed a recent project conducted by our team in Melbourne showing that treadmill exercise in mice following spinal hemisection leads to sprouting of the damaged axons and is associated with an improved walking pattern compared to non-exercised mice (Goldshmit et al. 2008). One possible mechanism for the improved motor function is the connection of the sprouting axons with propriospinal pathways. Dr Edgerton's group has shown that this is the case in a recent publication (Courtine et al. 2008). Another aspect of our discussion was the importance of limb loading. Release of bioassayable growth hormone (BGH) appears to be regulated by stimulation of proprioceptive neuromuscular afferents (Bigbee et al. 2000, 2006; McCall et al. 2000). In humans the release of BGH is impaired after periods of unloading of the limbs, e.g. after periods of bed rest (McCall et al. 1997) or space flight (McCall et al. 1999). Since the release of growth hormone with exercise could be a factor in modulating muscle and bone, it is of particular interest in people with SCI.

Dr Yuri Gerasimenko, who works with Dr Edgerton, has recently shown that a combination of epidural stimulation and the serotonergic agonist quipazine facilitates stepping after SCI in rats (Gerasimenko et al. 2007).

Suitability of rodents as models for SCI research

Are rodents the most suitable model for pre-clinical trials? Is research in non-human primates an essential step prior to human clinical trials of any therapeutic intervention? Dr Edgerton has recently published a paper with other eminent researchers advocating the use of non-human primates (Courtine et al. 2007) and is currently undertaking a study of task-specific training of hand function in monkeys following spinal hemisection. I met with Sharon, an engineer involved in development of instrumented tasks for the monkeys that enable measurement of force applied: One example is the Drawer Test in which the monkey pulls a drawer using his index finger to retrieve a peanut. Another is the task of grasping a grape from a curved spike; this enables 3-D force measurement. The curved spike ensures that the animal has to problem-solve to retrieve the grape. Kinematic analyses are undertaken using reflective markers on the

arm and hand. The SIMI program is used to automatically capture markers using high resolution and high speed digital cameras.

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Reed Neurological Research Institute, University of California Los Angeles

Dr Bruce Dobkin is Professor of Neurology and Medical Director, Neurologic Rehabilitation and Research Program, University of California Los Angeles, School of Medicine and Medical Center. He is a prolific author and researcher and Editor of the journal *Neurorehabilitation and Neural Repair*. Dr Dobkin was available for a brief discussion.

Issues discussed

Research into the effectiveness of rehabilitation

Dr Dobkin has published recent papers dealing with these issues (Dobkin, 2007, 2008), include the pitfalls in interpreting experimental observations in rodent models used for SCI research, the importance of developing explicit training paradigms, and the need for appropriate tests of function. He stressed the desirability of collaborations between basic and clinical scientists in the development of translational animal models of injury and repair.

Exercise for the upper limb following stroke

The dosage of therapy has not yet been clarified, and a dose-response study of intervention is required. He recommended one of his papers (Dobkin, 2005) as a template for undertaking such a study. We also discussed my paper (Galea & Darian-Smith, 1997) which showed that recovery of hand function in monkeys following spinal hemisection was dependent on corticospinal axons that crossed the midline below the level of injury. The questions remain: What do the crossing fibres do? Does exercise turn them on?

References

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ICORD, University of British Columbia Vancouver

Unfortunately, my visit to Vancouver coincided with the Society for Neuroscience Annual Meeting in San Diego so I was unable to meet the researchers from ICORD who were attending that meeting. I met with Dr Chris McBride who is the CEO of ICORD. This organization is part of the Translational Research Network and the Canadian Spinal Cord Injury Solutions Alliance. It has been well-supported by the Canada Foundation for Innovation and the BC Knowledge Development Fund, as well as with substantial endowments for Professorial Chairs.

The most impressive feature of this organization is its interdisciplinary focus. The key research activities are focused on:

- Investigation of mechanisms of neural development to identify new strategies for neural repair after adult CNS damage.
- Development of experimental therapies to facilitate functional repair of spinal cord and brain injuries.
- Evaluation of new clinical treatment and management paradigms, as well as maintain comprehensive patient databases and outcomes profiles.
- Designing and implementing assistive devices
- Improving reintegration and participation in the communities in which people with SCI live.

One important outcome is SCIRE (Spinal Cord Injury Research Evidence), (http://www.icord.org/scire/home.php) led by a physiotherapist, Prof Janice Eng, from the University of British Columbia, but with contributors from across Canada. ICORD also led the development of clinical trials guidelines for SCI for the International Campaign for Cures of Spinal Cord Injury Paralysis (ICCP), the Rick Hansen SCI Translational Research Network, and the Rick Hansen SCI Registry.

ICORD will soon move into a dedicated building, the Blusson Pavilion, located at the Vancouver General Hospital, which will house the researchers under the one roof and will include the hospital's Spine Clinic, integrated SCI outpatient clinics and the Rick Hansen Foundation.

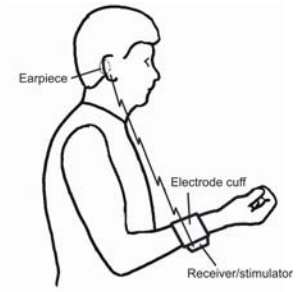
Other innovations include the application of the novel Technology Platform *Life at Risk*™ (http://www.riskanalytica.com/Solutions/LifeAtRisk.aspx), employed by the Canadian Strategy for Cancer Control, to spinal cord injury. Data from SCI patients will be used to populate the model.

The British Columbia Wheelchair Sport Association conducts a program called *Bridging the Gap*, designed to promote an active healthy lifestyle through physical activity and involvement in wheelchair sport (http://www.bcwheelchairsports.com/programs/btg.htm). *Have a Go* days offer new participants the opportunity to try wheelchair sports.

Division of Neuroscience, University of Alberta, Edmonton

Professor Arthur Prochazka

The main purpose of my visit to the University of Alberta was to discuss a collaborative research project with Prof Arthur Prochazka. This project involves the use of functional electrical stimulation technology developed by Prof Prochazka to train hand function in people with quadriplegia and has received funding from the Victorian Neurotrauma Initiative. I observed training and assessment sessions conducted by Sue Lin Chan, a Research Physiotherapist, to ensure standardization of these between the Canadian and Australian sites. The technology developed by Prof Prochazka, and to be used in our study, includes a wireless stimulator to enable or enhance grasp and release of objects, and an instrumented workstation called the *Rejoyce*.



Several small-scale studies have shown that the application of Functional Electrical Stimulation (FES) through surface electrodes to generate or assist grasping and releasing movements in quadriplegic patients results in improvements in grasp strength and in activities of daily living (Popovic et al. 1999; Popovic et al. 2006). Prof Prochazka has refined the application of FES by developing a muscle-stimulator garment that incorporates a wireless-triggered stimulator cuff, worn on the forearm and triggered when the user clicks his/her teeth (see Figure above). The tooth clicks (vibrations) are detected by an earpiece, similar to a hearing aid, which sends a radio signal to the stimulator cuff. This in turn stimulates the hand to open or close, allowing the patients to grasp and release objects. The stimulator system has been approved by the Canadian Standards Association.

Evidence from studies of patients with stroke suggests that skill acquisition and transfer of skills to other activities has been shown to be more effectively trained with the incorporation of context-relevant task-specific meaningful activities compared to rote exercise or passive modalities (Ma et al. 1999). FES-assisted hand exercises are therefore likely to be most effective when incorporated into specific grasping tasks. A standardised training program can be readily provided using a workstation. The *Rejoyce* workstation, developed by Prof Prochazka (See Figure at left) has several manipulanda requiring various types of grip (e.g. spring-loaded door knob; gripper, key), and provide the interface for playing several computer games. The technology is being commercialised by Rehabtronics (http://www.rehabtronics.com/).

References

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Other staff I met with included:

Professor Richard Stein

Prof. Stein developed the *Bioness L300 footdrop stimulator* with a heel switch. The *WalkAide* (http://www.walkaide.com/) is now available. This device has a tilt sensor which detects the angle of the shank in order to switch on the electrode stimulating the common peroneal nerve, thus eliminating the need for a heel switch. Recent research has shown that stimulation of the common peroneal nerve leads to increased corticospinal excitability (Knash et al. 2003). As a result the *WalkAide* only needs to be used intermittently.

Reference

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Dr Monica Gorassini

Dr Gorassini has conducted many studies of hindlimb motoneurons, spasticity following SCI and locomotor training following SCI. In her most recent work, she examined the mechanisms underlying muscle spasms in humans following SCI. Unlike non-injured controls, the motoneurons of subjects with chronic SCI respond with very long periods of pure depolarization in response to brief sensory activation. It is likely that these second-long EPSPs securely recruit slowly activating persistent inward currents in motoneurons that are known to mediate, in large part, the many seconds-long activation of motoneurons during involuntary muscle spasms (Norton et al. 2008). She also showed that improvements in locomotor function from treadmill training in patients with incomplete SCI are mediated, in part, by increases in corticospinal drive to muscles of the leg during walking (Norton & Gorassini 2006).

References

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Norton JA, Gorassini MA (2006) Changes in cortically related intermuscular coherence accompanying improvements in locomotor skills in incomplete spinal cord injury. *J Neurophysiol* 95(4):2580-9.

Professor Jaynie Yang

Prof Yang is in the Department of Physical Therapy at the University of Alberta and collaborates with the group in the Centre for Neuroscience. Her research interest is in the neural control of walking, and she uses the human infant as a model for investigating the control of walking without cortical control. She has shown that infant walking is similar to the walking in quadrupeds with respect to sensory control (Yang et al. 1998; Pang & Yang 2000) and most likely reflects the behaviour of the human pattern generator. She has recently published a paper reviewing the spinal and brain control of walking and the implications for retraining after SCI (Yang & Gorassini 2006).

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Dr. Karim Fouad

Dr Fouad is an Alberta Heritage Foundation for Research Senior Scholar in the Faculty of Rehabilitation Medicine. His research interests are in regeneration and recovery after spinal cord injury and he has previously worked in Dr Martin Schwab's research group in Switzerland. He has recently shown that the reticulospinal tract is necessary for recovery of walking in rats following SCI (Ballerman & Fouad 2006). His group has also developed a new electrode configuration for recording electromyographic (EMG) activity in behaving mice (Pearson et al. 2005). Since I was part of the research team that described the phenotype of mice that lacked the receptor EphA4, I was interested to discuss Dr Fouad's detailed behavioural analysis of locomotor activity in these mice (Akay et al. 2006). The receptor EphA4 is important for the correct development of the corticospinal tract (Dottori et al. 1998) and is also a potent inhibitor of axonal regeneration (Goldshmit et al. 2004). The behavioural data showed that the hopping movements of the hind legs in the EphA4-deficient mice were not always associated with synchronous movements of forelegs. These mice also showed shorter swing durations and swing amplitude (Akay et al. 2006).

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The Steadward Centre

While in Edmonton I visited the Steadward Centre with **Dr David Collins** who has an interest in functional electrical stimulation (http://www.steadwardcentre.ualberta.ca/). The Centre is located within the Faculty of Physical Education and Recreation at the University of Alberta. The Director is **Dr Donna Goodwin**, a leader in adapted physical activity. The Centre provides physical activity and sports programs to people with disabilities. Partners of the Centre are Alberta Sport and Recreation, Parks and Wildlife Foundation, Government of Alberta, MS Society of Canada and the Spinal Cord Injury Treatment Centre

The Centre runs several programs:

- Adapted Fitness Program for Adults
- Functional Electrical Stimulation (FES)
- Children and Youth Programs
- Athlete Development
- MS Active Now

A modest fee ($100-$125) is charged for a six-month membership entitling the member to attend the Adapted Fitness Program for Adults twice or three times per week. This may include FES-rowing or FES-cycling, yoga, or water-based exercise. The Centre has a well-equipped gymnasium with adapted exercise equipment. It has an active research program involving undergraduate and graduate students. Dr Goodwin's research focus is on health promotion.

Glenrose Hospital

I was also given a tour of the Glenrose Hospital by **Lorna Reimer** the Manager of the Occupational Therapy Department and had a discussion with **Dr James Razo**, Associate Director, Research and Technology. Key areas of research included:

- Assistive Technology
- Telerehabilitation
- Syncrude Centre for Motion and Balance, managed by **Dr Adrian Liggins**

I met with **Cherie Henderson**, an Occupational Therapist, who informed me that the hospital is one site for a multi-centre research project called Stroke Canada

Optimization of Rehabilitation by Evidence (SCORE-IT). The principal investigators (Mark Bayley, Sharon Wood-Dauphinee, Merrick Zwarenstein) are part of the Canadian Stroke Network.

Lyndhurst Centre, Toronto, Canada

Toronto Rehab has several sites, each managing specific conditions. The University Centre of Toronto Rehab provides rehabilitation for people with stroke and brain injury. The Lyndhurst Centre manages those with SCI. Another centre deals with people requiring complex care.

During my visit to Toronto, I visited both the University Centre and the Lyndhurst Centre. My program was as follows:

University Centre

I met with **Karen Brunton**, a Senior Clinician and Educator. Karen is also a qualified and experienced Bobath Instructor. Postgraduate students from the University of Melbourne have undertaken clinical placements under Karen's supervision. I was asked to give a seminar on rehabilitation of the arm after stroke.

Lyndhurst Centre

At Lyndhurst my host was **Dr Heather Flett** who is a clinical researcher at the Centre. Lyndhurst has 3 physiatrists, one for each 40 bed unit (120 beds). There are 300 admissions per year and around 5000 to 6000 outpatient visits per year. There are facilities for the *Proneuron* trial which is being conducted at several sites, including Craig Hospital, Shepherd Center, Mt Sinai Medical Center and the Kessler Center.

I met with the following people:

Dr Anthony Burns

Dr Burns is the recently appointed Medical Director of Lyndhurst. He was formerly Assistant Director in the Regional Spinal Cord Injury Center of the Delaware Valley, Philadelphia and had an academic appointment at Drexel University.

Dr B Catherine Craven

Dr Craven is a physiatrist who is interested in exercise and the prevention of bone loss after SCI. She is an author of the Chapter on bone health following SCI in the SCIRE Evidence database (Ashe et al. SCIRE). She has investigated the impact of body-weight supported treadmill training (BWSTT) on muscle and bone in acute SCI in a longitudinal prospective case series, showing that BWSTT appears to partially reverse muscle atrophy after SCI, but did not prevent bone loss (Giangregorio et al. 2005). In a similar study in individuals with chronic incomplete SCI she showed that 12 months of BWSTT resulted in an increase in muscle cross-sectional area but did not increase bone density (Giangregorio et al. 2006). Dr Craven has also been conducting research into whole body vibration, using both the Juvent 1000 and Wave™ vibration platforms, incorporated into standing frames. Her research in this area is still in progress, but her impression is that the Juvent platform provides an insufficient stimulus for bone in people with SCI. Her research has shown that long-term exercise training is feasible in the SCI population and that it results in significant improvements in physical and

psychological well-being (Hicks et al. 2003) probably mediated by changes in pain and stress (Martin Ginis et al. 2003). She has developed the Physical Activity Readiness Questionnaire (Martin Ginis et al. 2005).

Toronto Rehab will host the 3rd National Spinal Cord Injury Conference in November 2008 (www.sciconference.ca)

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Lyndhurst Exercise Centre

The gymnasium used by inpatients during the day is made available for the Exercise Centre in the evenings. It is staffed by one physiotherapist and is accessible to former patients who pay ~$25 per month for membership of the club. It is well-used and has a waiting list. The equipment is suitable for wheelchair dependent patients, and includes an *Equalizer 1000*, *Versatrainer, Vitaglide* and an *Uppertone*. The gym has a treadmill with BWS harness which is being used for research but also in clinical practice. A standardized wheelchair test course, developed by Dr RL Kirby of Dalhousie University is installed in the gym and is now being used to measure progress in a standardized way (http://www.wheelchairskillsprogram.ca/).

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Associate Professor Molly Verrier

A/Prof Verrier is leading the development of the GRASP measure for quadriplegic patients and wishes to encourage translational research, especially Phase I and Phase II trials. The international team involved in development of this measure includes therapists in the USA, Canada, Europe and Australia.

She has been involved in a range of studies including:

- Implementation of registry and data management– acute to post-discharge follow-up in the Cethrin trial. Cethrin is a Rho antagonist tested in acute SCI. The trial was conducted by Dr Michael Fehlings, University of Toronto (Baptiste & Fehlings, 2007).
- A study of motor cortex reorganization following SCI using fMRI (Jurkiewicz et al. 2007). This study followed 6 SCI patients for 1 year, beginning soon after injury. The task was a simple wrist extension task. During the sub-acute phase little task-related activation was observed within the primary motor cortex, but extensive activation was observed in associated cortical sensorimotor areas, more than in control subjects. As the person recovered, motor cortex activation increased and that of the sensorimotor areas decreased.
- Services delivered through WSIBM (Workers' Compensation) – equipment and services relating to employment.
- Trials of the Rehabilitation Engineering Laboratory Hand Function Test (Popovic & Contway 2003), which includes a test of the force exerted to hold a credit card using force sensitive resistors.

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Rehabilitation Engineering Laboratory and Assistive Technology Centre.

Unfortunately **Dr Milos Popovic**, the Head of the Laboratory was on leave during my visit. His research interests are in developing neuroprostheses for stroke and spinal cord injury patients, brain-machine interfaces, assistive technology and neurorehabilitation. I

was shown around by Cesar Marques-Chin, a PhD student working on development of a Brain Computer Interface using EEG signals.

Dr Popovic's current research is concerned with FES systems that can control complex tasks such as standing, walking and sitting balance. He has also developed some sophisticated measurement systems (Popovic & Contway, 2003, see above).

Tom Nantais (tnantais@bloorview.ca) has developed an on-line Library describing the assistive technology experiences of individuals with SCI from their own perspective (www.scipilot.com).

Seating Clinic

Marlene Adams and **Andrée Gauthier** are Occupational Therapists who manage the Seating Clinic.

Commonly used cushions include *Roho* cushions, *Nexus Spirit* hybrids and *Jay Custom* deep cushions. The hybrids work on a combination of foam and air. A newer cushion, the *Ride*, works by off-loading the buttocks and can be tested using sponges used for flower arrangements. The X-sensor system is used for assessment but has also been found to be excellent for patient teaching.

Transition

An Outpatient Services Coordinator manages transition so that outpatient services are coordinated and do not involve single referrals to single clinicians. This person looks at all the needs of the patient e.g. Physiotherapy, bladder function, seating etc.

A Community Integration Program involves a group program over 5 weeks, in which goals for return to the community are set. The group goes on outings together. Psychosocial adjustment to disability is discussed; the SW and psychologist deal with perceptions of disability. The problem is often housing and funding for patients with non-traumatic injuries. The Canadian Paraplegic Association has its offices at Lyndhurst and deals with consumer advocacy for patients, especially regarding attendant care services and peer-support programs. Peer mentors are provided for patients and eventually become part of the team. There is an Employment Resource Centre at Lyndhurst staffed by Human Resources Development Canada, which is used by outpatients. The province has an Assistive Devices Program which funds equipment for patients.

Judi Nash

Judi Nash is a physiotherapist who did her PhD with Professor AD (Bud) Cray on pain and is now a postdoctoral fellow at Lyndhurst. She is continuing her pain research in SCI patients. Bud Cray's hypothesis is that pain is an alteration of the homeostatic mechanism. The research uses a thermal grill, with temperatures alternating between 20^{o} C and 40^{o} C. These temperatures are innocuous on their own, but in combination can produce neuropathic pain. Judi runs an intensive course in pain management at the University of Toronto.

Craig Hospital, Denver, Colorado

Craig Hospital is a not-for-profit private rehabilitation centre dealing exclusively with spinal cord injury and traumatic brain injury. It is also one of 14 centres across the United States designated as a Model System Center for Spinal Cord Injury. The National Institute on Disability and Rehabilitation Research (NIDRR) provides funding "to establish innovative projects for the delivery, demonstration, and evaluation of comprehensive medical, vocational, and other rehabilitation services to meet the needs of individuals with spinal cord injury." (http://www.ed.gov/programs/sci/index.html).

The Centers contribute to a national database on patient data collected during the hospitalization phase and at regular intervals post-discharge, and are also expected to participate in independent and collaborative research and provide continuing education relating to spinal cord injury.

My hosts at Craig Hospital were **Ellen Severe**, Head of Occupational Therapy, and **Darrell Musick**, Head of Physical Therapy. My program was as follows:

George Richardson

George is Director of the Outpatient Follow Up Services. Craig Hospital deals with both SCI and Brain Injury. Both traumatic and non-traumatic SCI, including transverse myelitis, are managed at this Centre which has 90 beds with occupancy around 75 beds.

Follow-up for people with SCI is variable. Appointments can be made for 3-5 days per week. The Outpatient Team comprises a physician and two Nurse Practitioners, and dedicated PT and OT. Approximately 50% of inpatients and outpatients are from outside of Colorado. Follow-up will include Gastro, Bowel/bladder function, MRI. There are around 35-75 requests per year for those who have rehabilitation elsewhere. Case managers (usually nurses) are appointed to liaise with adjustors from insurance companies who dole out funds. The standard outcome measure is the FIM.

The philosophical position taken with regard to follow-up is that there must be time for patients to assimilate into the community. The patient's pre-morbid situation is taken into account, and for some it is a matter of "tough love". There are no readmissions for pressure ulcers, for example, as Community Wound Centres are supposed to deal with these.

Sharon Blackburn

Sharon is Senior PT. The Physiotherapy Program was completely revised about 12 months ago in order to incorporate new therapies such as FES cycling. Each therapist has five patients as well as a class, e.g. Be Fit for quadriplegics and Fit for paraplegics, Wheelchair Skills, Hydrotherapy etc.

Terry Chase

Terry Chase is the Nurse Educator who conducts a "Skills for Real-life" Class. Melissa Ceely a nurse from Queensland Health visited Craig last year. Re-entry classes are also conducted by Terry. The Education Centre is a spacious, comfortable area, accessible at all times by patients and carers, and contains books, journals, DVDs, CDs of all procedures.

Barb Page

Barb is the Director of Development at the Craig Foundation, which was established to raise funds to support the work of the hospital. A newsletter is produced for alumni, donors, insurance companies, other health care providers. An endowment raising initiative has been commenced to raise $50 million to support hospital programs such as Therapeutic Recreation, Patient Education, Complementary and Alternative Medicine. Some of these funds may underwrite some of the therapists' positions, patient assistance, research, Project EQL (Equipment for Quality Life) e.g. for home modifications or wheelchairs, re-evaluation programs for interstate clients. An annual giving program is currently limited to $170,000-$200,000. The endowment should reach $1million ($800,000 net after an annual educational dinner) and is intended to fund research.

A grant writer has been employed to apply for funding from US and Canadian funding bodies. This has raised around $600,000 for a wish-list e.g. the "Nurse of the Day" Program, SIM man, Patient Education program. FES cycles were funded by a corporation which provided $100,000.

Craig Foundation is one of the supporting organizations for a collaborative study on stem cells being undertaken by *Proneuron* and coordinated through the Karolinska Hospital (surgery is done at Craig). Another is a study being conducted by nurses on the use of magnets for pain relief. The research team is funded separately by the National Institute of Disability and Rehabilitation Research (NIDRR). Currently there is a clinician-led project investigating shoulder pain, but there was little information provided about this.

Amanda Carr

Amanda is an Occupational Therapist who conducts a class for high-level quadriplegic patients (15% of patients are ventilator-dependent). The class may involve the use of the *Motomed*, computer skills, slings and hoist education for families, COWS (Computers on Wheels), *Sip and Puff* mouse. A *Quadra mouse* is used in the mouth. *Head Spot*, *Eye-track* can also be used for control of the environment. Other classes involve communication (via computer), movement, e.g. driving the wheelchair, education (14 sessions) and outings.

Occupational Therapy manages FES for the hand. *Zynex* units from EMPI are used in this Department. These have clinical guidelines written by Lucinda Baker for the Rancho Los Amigos Medical Centre. Dr Dorie B Sokol from Emory University runs courses for OTs on Neuromuscular Electrical Stimulation. The *NESS H200* Hand

Rehabilitation System is used in the Outpatient Department (http://www.bionessinc.com/bioness_hand_main.php).

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Spasticity clinic

Mark Johannsen is one of two medical practitioners who conduct a weekly spasticity clinic. Both Botulinum toxin A and Phenol are used (phenol to motor nerves only).

Darrell Musick

Darrell Musick is Head of Physical Therapy and in charge of 31 Physical Therapists.

The Model System requirements are for standardised outcome measures to be collected on each patient. These are: FIM, ASIA, Muscle chart. Program Evaluation allows benchmarking against all centres using the UDS. There are Traumatic Brain Injury and SCI Model Centres. Funding from NIDRR supports researchers who must do research. At Craig the research projects being undertaken are:

- Measuring quantity of therapy against levels and outcomes, with 12 month follow-up. This project is being coordinated by Susan Horn, a statistician based in Utah who has developed tools to support clinical decision-making and conducts Clinical Practice Improvement (CPI) studies (http://www.isisicor.com/). She has conducted similar studies on stroke and joint replacement and is now conducting this study in SCI. She uses practice-based approaches, describing what is currently being done, how much intervention is provided and using standardized outcomes measures. The FIM is the primary outcome measure for this 3-year multi-centre study. Dr Horn has argued for alternative research designs for clinical studies rather than the randomized controlled trial, recommending CPI studies (Horn et al. 2005).
- Acupuncture
- Botulinum Toxin A for the management of spasticity
- Health and Wellness
- Ventilator weaning
- Traumatic Brain Injury

Darrell Musick runs courses on SCI through an organization called *Spinal Cord Injury Seminars* (http://www.sciseminars.com/), and would be happy to come to Australia to give one of these.

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Kelly Root

Kelly Root is a Physical Therapist (PT) who conducts the FES-cycle class. There are five FES cycles for between 50-55 patients. Between 20 and 30 people use these per week. An outing every other Friday interferes with the FES program. The bikes are wirelessly connected to a central computer so that each patient's program can be monitored and altered by the PT in charge of the class. The cycles have the potential to monitor heart rate and blood pressure. The bikes are manufactured by *Restorative Therapies Inc*. (http://www.restorative-therapies.com/), a company started by Dr John W McDonald, a neurologist and researcher who is Director of the International Center for Spinal Cord Injury at the Kennedy-Krieger Institute in Baltimore. The cycles are made by ERGO in Germany and assembled in Baltimore. *Restorative Therapies Inc*. has received FDA approval to make an FES Arm Cycle available for clinical use. The company representative is Judy Kline.

A Physical Therapy Assistant assists with the class, applying all the electrodes and setting patients up, while the PT is responsible for checking everything and turning the machines on. A PT must be present at all times during the class. A resistance of around 3Nm is typically used. There have been some concerns that using the bike reinforces muscle spasms, but this has yet to be confirmed in a systematic study. A daily record of each patient's program is kept. Patients with incomplete injuries are also using the FES cycles now, usually with a lower intensity of stimulation. Higher levels of stimulation are sometimes used as a negative reinforcement if patients start to reduce their rate of cycling. High ventilated quadriplegic patients are permitted to use the bikes, and their heart rate is monitored carefully.

A Rehabilitation Engineer representative from the company is very supportive and available on call to troubleshoot. If their prescription allows, patients are permitted to purchase a cycle to take home.

Joe Gomez

Joe Gomez is the Director of Recreational Therapy. One of the most impressive aspects of Craig's program is the Recreational Therapy Program. Staff are rostered from 8am till late evening 7 days per week. Nurses accompany staff and patients on most outings and carry an emergency kit and drugs, as the rules are that only a nurse is permitted to dispense medication. The hospital has access to many outdoor sites, including those reserved for VIPs, such as a nearby lake. There are generally 3-4 outings per week and at weekends. These include trips to the cinema, to restaurants, shopping etc. often using public transport. Craig has its own bus. Once per year everyone will go sailing. Recreational Therapy is programmed into the patients' schedules. A critical factor is getting patients to try certain pastimes as early as possible. Even the most exacting of hobbies might be possible with adapted equipment. A staff member who is paraplegic runs a workshop dedicated to making one-off aids for patients for their hobbies or their wheelchairs.

Volunteers

In Denver, schools have a Volunteer Service, where it is a requirement for students to undertake some community work. Some students from nearby high schools will choose to spend time helping at Craig. Parents of patients and other adults will also volunteer and can indicate the type of work they are prepared to do, e.g. one volunteer will only drive the bus. A Volunteer Coordinator coordinates this program. Once per year all volunteers are invited to a gala dinner at a local Country Club to thank them for their efforts.

Miami Project, Miami, Florida

My visit was interrupted by the Thanksgiving Holiday on Thursday 22nd November with a public holiday on Fri 23rd November. My host was A/Prof Edelle Field-Fote. I was asked to give a presentation entitled: *Regulation of glial scar formation and axonal regeneration by EphA4.*

The Miami Project is now in a new purpose-built building, next door to the Jackson Medical Centre which is the County Hospital. My program was as follows:

Dr Christine Thomas

Dr Thomas is a physiologist who is investigating single motor units in the paralysed thenar muscles in people following SCI. At post-mortem, ventral roots have been shown to have thin myelin with poor conduction velocity. Does activity promote remyelination? Is the position of a quadriplegic patient's hands and arms likely to increase pressure on the ulnar nerve at the wrist or at the elbow and lead to a chronic peripheral nerve injury?

Dr Thomas has found that thenar motor units are fatiguable and the thenar muscles retain a population of motor units with heterogeneous contractile properties (Häger-Ross et al. 2006). Frequencies are low and asynchronous, which is indicative of demyelination or poor remyelination. The excitability of thenar motoneurons declines substantially (to 33%) over 90 s of stimulation (Butler & Thomas 2003). FES protocols used to produce functional movements in paralysed muscles need to accommodate the significant and rapid fatigue of the motor units (Klein et al. 2006).

We discussed the potential clinical use of vibration. Vibration provides a complex cutaneous and muscle spindle afferent input. Vibration of the triceps tendon for 5 s drives the 1a afferents and increases force – 80Hz is optimal. At the University of Otago Dr Thomas used to have a vibrator, made by a Japanese company, that allowed control of frequency, but apparently these are no longer available. Dr Thomas investigated the effect of vibration of the Achilles tendon on involuntary muscle contractions, which are common after SCI and may be due to increased sensitivity to Ia muscle afferent input. Vibration reduced electromyographic activity and this was unlikely to be mediated by changes at the Ia synapse or motoneuron since the magnitude of the soleus H reflex remained the same. Thus vibration may be clinically useful in controlling involuntary muscle spasms after SCI (Butler et al. 2006). In another study she showed that vibration of the triceps muscle in people with SCI induced a tonic vibration reflex at rest in half of the triceps muscles tested. Elbow extensor MVC force was also enhanced. Thus vibration could also be used to increase the contraction strength of triceps brachii muscles (Ribot-Ciscar et al. 2003).

Dr Thomas also recently investigated muscle spasms in patients over a period of 24 hours using an 8-channel recorder. Baclofen seemed to make no difference to number of spasms. It is possible that patients are on too high a dose of baclofen.

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Dr Eva Widerström-Noga

Dr Widerström-Noga's research is concerned with pain after SCI. Her current experiments deal with epidemiology and assessment of the pathophysiology and psychology of pain. It is important to assess all types of pain including neuropathic pain, e.g. back pain may be nociceptive or neuropathic. Quantitative Sensory Testing (QST, see review by Chong & Cros, 2004) is used as a standardized outcome measure. Time series analysis is used for data analysis. Pain does not have to be cured, but managed.

Dr Widerström-Noga has used the Multidimensional Pain Inventory (MPI) for assessing pain impact after SCI (Widerström-Noga et al. 2002). She has now developed a spinal cord injury version of this tool (MPI-SCI), eliminating the questions related to work and modifying the activity scale to take account of decreased activity levels due to pain, and has now validated this tool (Widerström-Noga et al. 2006). Dr Widerström-Noga was on an international panel that determined a set of standardized measures of pain in people with SCI (Bryce et al. 2007).

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Dr Mark Nash

Dr Nash is investigating risk factors for heart and vascular disease in people with SCI. Dr Nash has a spinal cord-injured doctoral student who is investigating ongoing exercise in SCI. The recreational therapist also has a spinal cord injury and an important role model. He manages the gymnasium for the Miami Project (see left). Patients who participate in research are permitted to use the gym without charge. It provides a social as well as an exercise outlet.

The Miami Project was one of the centres involved in the Model Systems Program, but is not currently involved. The Model Systems Program commenced in 1972, however the dataset is not complete as it includes only the interventions and outcome measures used at the Model Centres, nor is it representative as it includes only those with closed traumatic injuries. There is a need to account for change in care and funding over time. NIDRR provides funds for the data collection task. Although multicentre collaborations are encouraged, the system is rather bureaucratic. NIDRR has input from consumers via a consumer panel.

Dr Nash has shown that exercise is important for good health after SCI (Nash 2005, 2006; Nash et al. 2002, 2007). He is an advocate of circuit resistance training (CRT) which comprises three circuits of six resistance stations encompassing three pairs of agonist/antagonist movements (e.g. overhead press and pull) and three 2-minute periods of arm cranking. Each session lasts 45 minutes and should be done three times per week (Nash, 2006). Such a program has been shown to improve cardiorespiratory fitness and strength (Jacobs et al. 2001), but also reduces cardiovascular risk (Nash et al. 2001). He believes in making exercise interesting, for example the boring arm cranking exercise is much more motivating when combined with virtual reality in the *GameCycle*, an exercise device that promotes physical fitness for people with lower-extremity impairment. The device consists of a videogame console interfaced with an arm cycle, which is used to control a racing game. The *GameCycle* is commercially available from *Three Rivers* (http://www.3rivers.com/GameCycleGateWay.php).

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Dr Mary Bartlett Bunge

Dr Bunge's late husband, Dr Richard Bunge was Director of the Miami Project. Dr Bunge's research is concerned with cellular approaches to regeneration, including the use of Schwann cells and olfactory ensheathing cells.

Dr Dan Liebl

Dr Liebl's research is concerned with Eph receptors, stem cells and adult neurogenesis. EphA4 is also a death receptor. If the ligand EphrinB3 is not present, the receptor functions as a death receptor. Caspase 3 activity leads to cleavage of the intracellular domain, and the increase in caspase activity leads to cell death. If the ligand is provided the cells do not die (Ricard et al. 2006).

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Dr Edelle Field-Fote

Dr Field-Fote was a Visiting Fellow in the NSW Spinal Cord Injury and Related Research Program in 2007. She is currently undertaking a study comparing different types of locomotor training for people with incomplete SCI. The four types of training are: robotic training using the *Lokomat*, body weight-supported treadmill training with therapist assistance, body weight-supported treadmill training with peroneal nerve stimulation and overground walking combined with peroneal nerve stimulation. Preliminary analyses indicate that locomotor outcomes appear to be comparable across training approaches (Field-Fote et al. 2005). Training using a combination of body weight-supported treadmill training and peroneal nerve stimulation results in improved intra-limb coordination (Field-Fote and Tepavac, 2002). The findings of Choi & Bastian (2007) highlight the adaptability of human walking and provide a rationale for locomotor training.

Peroneal nerve stimulation during walking is provided by a *WalkAid, NESS L300*, or *ODFS (Odstock footdrop stimulator*) and is done to stimulate the flexor withdrawal reflex: Blood pressure is measured prior to training, and patients wear a polar monitor to monitor heart rate. The electrode aims to stimulate the deep peroneal nerve just below and just in front of the fibular head.

The locomotor training project will soon be extended to children with SCI and this will be undertaken by **Kathleen Manella**, a PhD student in the Lab. It is proposed that the children will attend a camp, such as the *Shake-a-Leg* camps for children with disabilities, so that they can receive the intensive (daily) training.

Larisa Hoffman, who recently completed her PhD, has conducted a study of task-specific training in 24 people with quadriplegia. The two interventions were massed practice with somatosensory stimulation and massed practice with no stimulation. Patients needed to have intrinsic muscle function to participate. Median nerve stimulation (500 ms train, 10 Hz, 1 ms pulse duration) was delivered at the intensity eliciting a motor threshold response. Training sessions were 5 days per week for 3 weeks and 2 hours per session. Massed practice of the following tasks was undertaken: Grip, Pinch, Pinch with Rotation, Grip with Rotation and Gross Upper Extremity Movement. Outcome measures were:

- Wolf Motor Function Test
- Motor Activity Log
- Jebsen Taylor test
- Chedoke Arm Inventory.
- Semmes-Weinstein monofilaments
- TMS mapping. This is done using 200 stimuli at 90%. Recruitment curves can be obtained with 50 stimuli. The cap is a loosely fitting cap tied under the chin and the TMS coil is held with a clamp. The outcomes measures used were a) Excitability threshold: 50-100μV MEPs in 50% of consecutive stimuli; b) MEP amplitude at 100% (maximal stimulation output).

While both groups showed improvement, the combination of massed practice with sensory stimulation resulted in greater increases in pinch strength and timed functional test scores than massed practice alone (Beekuizen & Field-Fote, 2005). A case study of one subject in the program (Hoffman & Field-Fote, 2007) reported improvements in sensory function, strength, and hand function. These were accompanied by changes in the size and location of the cortical map of the Biceps muscle.

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Dr W Dalton Dietrich

Dr Dietrich is the Director of the Miami Project. His research interests are in the area of inflammatory, genetic and chemical changes that occur after injury that could be targets for intervention (Fleming et al. 2006).

He has used the technique of 2 deoxyglucose (2DG) after a cortical or SCI contusion injury in the rat to show that activation is depressed after injury. Stimulation of the whiskers increases the level of activation on both sides of the brain, indicating early biochemical changes. The effect of a cortical lesion is to depress cortical activity for whiskers on both sides. The effect after SCI remains to be seen. The 2DG technique might be a useful marker of preservation of cortical activity post-injury.

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Shepherd Centre, Atlanta Georgia

My host was Dr Mike Jones, Vice-President, Research and Technology and Director, Virginia Crawford Research Institute.

The Shepherd Center has 100 beds, soon to be 120 beds with current renovation and expansion, including a 10-bed intensive care unit and a 30-bed acquired brain injury unit. The Center has had continual funding through the National Spinal Cord Injury Model System since 1982. In addition to spinal cord injury, the Center manages people with multiple sclerosis, tranverse myelitis, and Guillain-Barré syndrome. The length of inpatient stay is very short, approx. 4 weeks. A coordinator is assigned to each patient on admission to facilitate transition. The Center houses families for 30 days without charge while the client attends the Day Program (Outpatient Program).

In addition to the Physical and Occupational Therapy Departments it has:

- Therapeutic Recreation Department. The Therapeutic Recreation Department at the University of Georgia conducts student projects at Shepherd.
- Education Centre/Library containing medical textbooks and journals
- Assistive Technology Centre
- Driving: Michelle Luther-King Occupational Therapist
- Fitness Centre called Promotion. Membership includes local businesses and staff.
- Rehabilitation Engineering: Two engineers build wheelchairs to fit clients.
- Beyond Therapy: An exercise program conducted 3 hours per day; 3 days per week.
- All wards are equipped with TVs with 'sip and puff' capability, so a patient has control immediately, as well as patient hoists, so no lifting of patients is done by staff.

Involvement of clinicians in research:

The educational and research projects at the Shepherd Center are geared to the amount of time and expertise available. There is a Journal Club: 8 journal clubs over 6 months. Research ideas need funding for the project as well as time release. **Sarah Morrison**, a Physical Therapist and the Inpatient Program Director, has joint responsibility for managing research together with the SCI Research Director. **Dr Debbie Backus**, a Research PT, now an Assistant Professor in the Department of Rehabilitation Medicine at Emory University, conducted a series on research called *Bagels and Research*. These were held at lunchtime 12.15-1pm, with bagels provided, and comprised discussion of the literature on topics such as spasticity (communication with physicians and clinicians regarding outcome measures), basic research, pathophysiology, benefits and barriers, e-stimulation for weak muscles (which parameters are important?), outcome measures for

clinicians (e.g. pain, survey of practice). A Research Course (*Research is not Rocket Science*) comprising 9 sessions once per month was conducted between 4-6pm. This was modular (one hour lecture and one hour problem-solving), and included topics such as literature searching and critical review.

The career ladders for clinicians are another driver for the conduct of clinical research. Those clinicians at Steps 4 and 5 are required to do a small research project which can be presented at a conference or published in a peer-reviewed journal. Cash awards are given for papers published. The administrators support clinicians in their research endeavours by allowing some dedicated research time. Clinicians participate in research mainly through involvement in recruitment/selection of patients and undertaking measurement of outcome, e.g. ASIA, videotaping pendulum test. Clinicians attend research meetings so that they are informed about planned research and research in progress, and are able to contribute to these sessions. The Program Directors are supportive of this. There are dedicated Therapist Educators/Managers who are active in research projects.

Research Projects:

- The Shepherd Center has developed the infrastructure for conducting clinical trials, mainly drug trials, with dedicated clinical trials staff, including a Director (Issi Clesson), 12 clinical trial coordinators and a regulatory liaison person.
- *Rehabilitation Engineering Research Center (RERC) on Wireless Technologies*, which was launched in 2001, as a research partnership between Shepherd and Georgia Institute of Technology (Georgia Tech), to explore new applications of emerging wireless technologies to the needs of people with disabilities. It recently received a grant of $4.75 million from NIDRR.
- *NeuroRecovery Network*. Shepherd is one of seven centres nationwide participating in this program. Shepherd provided funding for the Body Weight Training System Treadmill and further funding has been received from Christopher and Dana Reeve Foundation and the Centers for Disease Control and Prevention. This program is currently targeted to outpatients only and 180 patients have been recruited to this project so far. (http://www.christopherreeve.org/site/c.geIMLPOpGjF/b.3757417/k.7B13/NeuroRecovery_Network_NRN.htm). Sarah Morrison and Debbie Backus recently published a paper on the financial feasibility of conducting locomotor training as performed in the *NeuroRecovery Network* program (Morrison & Backus, 2007).
- *National Spinal Cord Injury Model System*: Data on SCI patients admitted to Shepherd are routinely collected, and then trained personnel perform telephone interviews with patients to collect further data at 1, 5, 10, 15 and 20 years after injury
- Multiple Sclerosis: Cognitive testing and MRI
- Medtronic: Use of baclofen pump
- Traumatic Brain Injury: Attentional strategies and pharmacological treatment following trauma
- Factors associated with outcomes, coping and adjustment
- Investigation of seat bucket slope and support. A four-leaf sensor array sensitive to weight shift is being used to examine this (**Dr Chris Maurer**).

- The First Five Project is being conducted by Susan Sheehy RN at the South Shore YMCA, Quincy Massachusetts. It was initiated by the NorthEast Spinal Cord Initiative (NESCI), and is sponsored by the Massachusetts Hospital School and the Beth Israel Deaconess Medical Center. The aim of the project is to assess a high-intensity, focused exercise program for adolescents and adults with spinal cord injuries. Funding has been provided by the Travis Roy Foundation and a grant from the Christopher Reeve Paralysis Foundation. (http://www.travisroyfoundation.org/FirstFive/default.htm).
- *Model Systems Projects*: The Shepherd Center uses the Model Systems funding to conduct research on quality of life, adjustment to injury, secondary complications and community reintegration issues.

Dr Mike Jones recommended recent publications of collaborative projects undertaken by Gary Dudley and Edward Mahoney, from the Department of Kinesiology at Georgia University and the Virginia Crawford Research Institute at the Shepherd Center.

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Physical therapy program

The Inpatient component is short (~ 4 weeks). The Day Program is a comprehensive outpatient service, with patients attending 5 days per week for a full day. If patients need only one form of therapy, e.g. physiotherapy, then they will attend less frequently, perhaps 3 times per week. The cost is around $750 per week for approximately 9 weeks. All patients are appointed a counsellor, whom they see once per week, to deal with adjustment after injury, sexuality etc.

There is an outing scheduled each evening, supervised by a nurse, with 15 patients attending. The outings are sponsored by donated funds. After discharge patients can attend ski trips or learn scuba diving, as well as many other activities.

Community Bridge Program

This is a community re-entry support program funded by Marcus to the tune of $8 million. A Case Manager works with the inpatient and/or the day patient team to implement the discharge plan, especially regarding community services. There is a need to build competencies in the community and recruit local providers, as it is difficult to find appropriate providers and home health care in the community. Therapeutic Recreation staff also work with individual patients in their home community. No research has yet been undertaken evaluating the impact of this program.

Beyond Therapy Program

The Beyond Therapy Program is somewhat similar to the First Five program, comprising strengthening and balance/coordination exercises. **Candy Tefertiller** and **Paula Ackerman** are the PTs in charge of the program and there are four exercise physiologists. The cost of the *Beyond Therapy Program* is $83 per hour, and patients attend between 9-15 hours per week for 24 weeks. There is a sliding scale of payment and patients must pay up front for treatment slots, which they lose if they do not attend. It is considered to be important that there are consequences for non-attendance. The PT plans the program, which addresses functional mobilization needs. The exercise physiologist conducts exercises focused on strengthening and cardiovascular function. Activities included in the program are: locomotor training using the *Parastep*® system (http://www.musclepower.com/parastep.htm), FES walking using L300 Bioness or *WalkAide* Stimulators; FES –cycling, E-stim for strengthening quadriceps and triceps. There are currently 26 patients in the program. Further funding is being sought for the program. Outcome measures include: ASIA, FIM, SCIM (because of ceiling on FIM).

The Beyond Therapy Program is cited on a website developed by the Icelandic Health Authorities and the World Health Organization (WHO) with the support of the Council of Europe. This website contains information on various therapies and procedures that have the potential to restore function in people who have sustained a spinal cord injury (http://www.sci-therapies.info/introduction.htm).

Georgia Institute of Technology (Georgia Tech)

Stephen Sprigle, a Physical Therapist and Engineer, is Director of the Center for Assistive Technology and Environmental Access (CATEA). He discussed several gadgets that could be used to monitor physical activity such as:

- *Phidgets*: a set of "plug and play" building blocks with USB interface for sensing and control from a PC.
- *Sparkfun*: an inexpensive triaxial accelerometer
- *SFE Widgets datalogger*, with a full size SD card and a quarter size SD card, can record activity for weeks.
- A *LilyPad triaxial* accelerometer is a wearable e-textile technology designed to be sewn into clothing and is washable.
- *Polar activity watch* (AW200), can detect movements of the body and distinguish their intensity in order to calculate energy consumption.

- Shoe-borne accelerometers can also be used to monitor gait.

Stephen Sprigle is using technology to investigate movement of SCI patients during a task such as transferring between the wheelchair and a mat. Reflective markers placed on garments that can easily be put on or removed were used to model body movement. Real-time animations are used to assist the patients' training in transfers, as well as to characterize the movement patterns used by patients, including measuring the height of the buttocks, the placement of the hands, the rotation between the hips and shoulders, and the timing of each movement.

Wat (Postdoctoral Fellow) and Kristy (PT researcher) are using DARTFISH video software solutions (http://www.dartfish.com/en/media-gallery/videos/index.htm) to evaluate videotapes of movement. The software enables analysis of movement by measuring time, distance angles and velocity. It could be a very useful clinical tool, as there is no need for reflective markers.

Maureen Linden is a research engineer at CATEA. Her current research includes seating, and detection and prevention of pressure ulcers and deep tissue injury.

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Kentucky Spinal Cord Injury Research Center and Frazier Rehabilitation Hospital, Louisville Kentucky

Kentucky Spinal Cord Injury Research Center

The Director of the Kentucky Spinal Cord Injury Research Center (KSCIRC) is Dr Scott Whittemore, formerly of the Miami Project. Dr Christopher Shields, Neurosurgeon and Clinical Director, had the original vision and recruited Scott to Kentucky from Miami. Dr Susan Harkema, a physiologist formerly at UCLA, is the Director of Rehabilitation Research. The senior staff all have endowed Chairs and a University of Louisville appointment.

Dr Scott Whittemore

Dr Whittemore set out to build the basic science research at KSCIRC by appointing key senior people, however there is a commitment to supporting and nurturing the junior faculty by including them on grant applications and through collaboration. The KSCIRC has strong core facilities for basic science: microscopy, surgery, behavioural and electrophysiological testing. The Center strives to foster interaction between surgery, basic science and rehabilitation.

Dr Theo Hagg

Dr Hagg, a Senior Scientist at KSCIRC, is investigating angiogenesis following injury using intravenous injections of a lectin (Benton et al. 2008) and neurogenesis using CNTF (ciliary neurotrophic factor) (Yang et al. 2007).

Dr David Magnuson

Dr Magnussen is Senior Scientist at KSCIRC. He has shown that axons in the lateral and ventrolateral funiculus of the spinal cord carry ascending and descending propriospinal axons that are spared following contusion spinal cord injuries (Reed et al. 2006). He has also shown that reticulospinal projections project to multiple spinal cord segments and many cross the midline below T9 (Reed et al. 2008). His group has also developed a test of swimming ability to evaluate return of lower limb function in animals following SCI (Smith et al. 2006, 2008).

Another very interesting avenue of research is examining the effects of activity-based rehabilitation following SCI. Four different approaches are being investigated. One group of rats is placed in a wheelchair to reduce activity of the hindlimbs. These animals are provided with daily passive movements. The other programs include swimming, shallow water walking, and treadmill training with body weight support.

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Frazier Rehabilitation Institute

The Frazier Rehabilitation Institute is a regional health care system serving Kentucky and southern Indiana. A 15-story, 135-bed Rehab and Neuroscience Center was opened in June 2007. Spacious patient rooms each have their own private bathroom and internet access. There are therapy gyms on each floor. In addition to the Spinal Cord Medicine Program there are Stroke Recovery, Brain Injury, Orthopaedic Rehab, Occupational Rehab and Pulmonary Rehab Programs.

Spinal Cord Medicine Program

Rather than individual departments such as Physical and Occupational Therapy Departments, the Institute has Inpatient and Outpatient Care Programs. Inpatient and Outpatient Directors of Therapy Services coordinate Physical and Occupational Therapy and Speech Pathology. Inpatient admissions and outpatient care are managed through a central hub operating a triage process. The core team comprises a physician, nurse coordinator, and care-coordinator (involved as soon as possible for patient discharge planning, education and evaluation). Marketing, information, research are also coordinated through this process, for example, making appointments for assessment at the appropriate times. All patients are listed in a database. SCI patients are given a single 1800 number that provides access to the care coordinator and nurse assistant.

When patients are discharged from the Inpatient Program they return to Frazier 5 days per week for therapy for about 4-6 weeks, then transition to the Outpatient Program. The Day Rehab program is a transition program in which outpatient therapy is provided in 2 to 3 one hour-long sessions per week. Insurance limits these sessions to 20-40 patient visits per year.

Community Fitness and Wellness Facility

A new Community Fitness Program has been developed, the first in the *NeuroRecovery Network (NRN)*. The start-up of the project was funded through support from the Frazier Hospital and existing equipment and gym space are being used. Grants for equipment were obtained from the Christopher Reeve Foundation (NRN), the Centre for Accessible Living, and the Healthy Kentucky Initiative.

The Community Fitness Center is open from 5-8 pm on weekdays. Weekend opening is planned from 8-4 pm each day. General and specialized packages are available, starting with a base cost of $50 per month for use of standard gym equipment. Several programs are offered: e.g. Gym program, FES, Locomotor Training etc. Extra costs are incurred for extra programs and for personalized attention. Some people have Locomotor Training 2-3 times per week. If a specialized package with a trainer is required, the fitness plan is based on the client's goals. An extra fee is payable for the trainer ($40 per hour), who is usually an exercise physiologist or athletic trainer. Adjustments to the program are made after 6-8 weeks.

Equipment in the Center includes*:*

- *Guldmann Lifts* (http://www.guldmann.com/) were installed in therapy and laboratory areas to permit safe lifting of patients.
- *Vital Stim* (NIH Project: Speech Pathology)
- *Pilates Reformer*
- *Dyna Disk* (half ball)
- *Tilt-a-Gym*
- *Rickshaw Exerciser* (http://www.sammonspreston.com/Supply/Product.asp?Leaf_Id=2110).
- *Tuff Stuff Cable Crossover* (http://www.tuffstuffitness.com/commercial/www.tuffstuff.net/product/ps-250-cable-crossover-2x150-lbs.html).
- *NuStep* (upper extremity cycle http://www.2ndwindcommercial.com/nustep.html)

Therapeutic Recreation

The Therapeutic Recreation staff manage the Community Fitness Program. They do not develop care plans for functional goals, but they do have client-centred goals, which include weights, strengthening, fitness, core strength etc. They are also involved in locomotor training which is done with the assistance of two rehabilitation technicians and students, and a lead technician who is responsible for scheduling and supervision.

Jill Farmer is the Manager of Therapeutic Recreation and Adapted Sports Programs. She assists clients with their hobbies and manages a Sports Program, and a Parks and Recreation Program. A mentor program for patients includes wheelchair athletes as mentors.

Seating and Assistive Technology are coordinated in one clinic by the Rehabilitation Engineer. Vocational Rehabilitation is a state-based program.

Dr Susan Harkema

Dr Susan Harkema manages the *NeuroRecovery Network*, funded by the Christopher Reeve Foundation, and is a proponent of Locomotor Training (Behrman & Harkema, 2007; Dobkin et al 2006, 2007; Krassioukov & Harkema 2006). This includes training of standing, stepping and walking. Standing training can be facilitated using electrical stimulation. Stepping and walking training are commenced using body weight-support on a treadmill (see left). No arm support is permitted. Four staff are required: one to control the treadmill, one to facilitate at the pelvis, and the other two to move the lower limbs. The handling is quite precise, providing appropriate sensory cues. At Frazier and elsewhere, the staff members typically involved are: a Physical Therapist and three Rehabilitation technicians (or two Rehabilitation Technicians and a volunteer). The training comprises short bursts of walking of 1-2 minutes duration, so the patient receives a total training time of 20-30 minutes. The staff regularly rotate their positions so that occupational injures are minimized. This type of training is followed up with over-ground and community ambulation training.

Outcome measures recorded every 20 days are: Berg Balance Scale, WISCI, Tinetti Balance Scale, 10 metre walk, 6 minute walk. Other outcomes of interest are changes in trunk control and sitting balance, spasticity, and clonus, as well as changes in sympathetic nervous system function, lung function, blood pressure (whether less hypotensive), and cardiac function. Additional measures include the brain control motor assessment (BMCA) to be conducted by **Dr Barry McKay** who developed this test in conjuction with Dr Arthur Sherwood and Dr Milan Dimitrijevic at Baylor College of Medicine in Texas (Sherwood et al. 1996; McKay et al. 2004; Lim et al. 2005).

FES-cycling is used for people who are ASIA A, and those who are not expected to achieve walking in the next 6 months. Hydrotherapy is provided and one of the pools has an underwater treadmill.

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Linda Shelburne, Director of Outpatient Program

The goal of activity-based therapy is not necessarily walking. Patients with complete injuries develop head control and trunk control. Others improve their ability to transfer via weight-bearing through the legs. Locomotor Therapy has now been introduced into the Inpatient environment (**Cathy Parker**, a Speech Pathologist, is Director of the Inpatient Program). To be eligible for the program patients must be off medication (baclofen) - this is a challenge and requires careful negotiation with the medical practitioner.

Staff training

Involvement in the *NeuroRecovery Network* (or Activity-based Therapy) required 5 weeks of preparation for 6 staff members who took the opportunity to refresh their knowledge of neurophysiology. An Outpatient model was used, the program commencing with 3 patients and then building up to a full day load within a couple of months.

Linda offered to provide training for Australian staff interested to learn how to conduct Locomotor Therapy. The team involves four people: one PT plus three Rehabilitation Technicians or Physical Therapy Assistants. The Rehabilitation Technicians commonly have an exercise science background as they understand the principles of training.

The cost is $40,000 for 60 visits. The Cost Utility, though not formally calculated, can be understood by an example. A T4 level patient who may end up walking will save costs in the long run because he will not require continual upgrading of wheelchairs, and may not need catheterization. Use of the FIM as an outcome measure for Locomotor Therapy is not considered informative in the SCI population; therefore one needs more sensitive measures such as the Berg Balance Scale, the Tinetti Scale, 10 m walk, 6 min walk tests.

Jamie Oschner, PT supervisor

Standard physical therapy programs tend to focus on compensatory activities. Non-functional positions are used, and the little amount of standing that is done is always static. After Locomotor Therapy, patients report being able to breathe better, and a better quality of life, better posture and some return of bowel and bladder function. Inpatients have often needed a power wheelchair to begin with, and then graduate to a manually assisted chair or a manual chair. Patients need to be taken off anti-spasmodic medication prior to training. Typically they report feeling better off medication, and often need only 5-10 mg at night to aid sleeping.

The view of the therapists is that appears to be no carryover from standard stretching on the mat, therefore it is better to carry out stretching in weight-bearing positions. A typical treatment session will involve: 45-60 min on treadmill, practice of sitting balance, 15-30 minutes on the mat.

Steve Ahr, Administrator and Vice-President, Case Management

Frazier has 95 beds in a new building opened in 2002. Research funding is from NIH and Christopher Reeve Foundation. The patient stream for research comes from those treated at Frazier Rehabilitation Institute. The 75:25 rule applies for Medicare reimbursement for treatment. One cannot fund a patient group of this size using NIH funds, therefore provision of treatment for patients provides an income stream.

New developments include a *cine-flow MRI*, a novel imaging technique which will be linked with ASIA scores and electrophysiology; also *near infrared oximetry* near the lesion site.

University of Pittsburgh, Pittsburgh, Pennsylvania

The purpose of my visit to Pittsburgh was to meet with Dr Peter Strick, Center for the Neural Basis of Cognition, University of Pittsburgh. Dr Strick has developed a novel method of investigating nervous system connectivity using rabies virus. I was invited to give a presentation: *Axonal regeneration in EphA4-deficient mice.*

I met with the following people from the Department of Neurobiology at the University of Pittsburgh:

Jean-Alban Rathelot

Dr Rathelot has used rabies virus to study corticomotoneuronal connections to intrinsic hand muscles in the primate (Rathelot & Strick 2006). The corticomotoneuronal cells are located in the caudal part of the primary motor cortex, buried in the central sulcus. The cells for one muscle are distributed very broadly throughout the full mediolateral extent of the arm representation, and there is extensive overlap between the territories for different muscles. The corticospinal cells located on the dorsal surface of the primary motor cortex project to interneurons.

Dr Donna Hoffman

Dr Hoffman was involved in a classic experiment investigating whether 'muscles' or 'movements' are represented in the primary motor cortex (Kakei et al. 1999). She has also examined the plasticity of skill learning as represented in the motor cortex (Yamamoto et al. 2006).

Dr Nathalie Picard

Dr Picard has examined the changes in the functional organization of the primary motor cortex associated with the acquisition of motor skills. She showed that practice changes the response properties of neurons in the primary motor cortex (Matsuzaka et al. 2007).

Dr Richard Dum

Dr Dum has used the rabies virus to examine the organization of basal ganglia and cerebellar projections to the supplementary motor cortex (Akkal et al. 2007) as well as the organization of the projections from the cerebellar dentate nucleus to motor and nonmotor areas of the cerebral cortex (Dum & Strick 2003). He is currently investigating cingulate and insular projections of pain axons.

Dr Andrew Schwarz

Dr Schwartz is a systems neurophysiologist who capturing the brain transmissions involved in a person's intention to move the arm and translating them into command signals to drive prosthetic limbs. This is based on the fact that there is a simple and robust relationship between activity in the motor cortex and kinematic parameters of movement. The work has progressed to the point that monkeys can now use recorded signals to control motorized arm prostheses to reach out grasp a piece of food and return

it to the mouth. This work has huge potential application to rehabilitation (Schwartz, 2004, 2007, Schwartz et al. 2006).

Dr Aaron Batista

Dr Batista is a Bioengineer whose interests are also in neural prosthetics. He is exploring how provision of sensory feedback can assist in the control of a neural prosthesis (Batista et al. 2007, 2008).

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Mt Sinai Medical Centre, New York

The Mount Sinai Spinal Cord Injury Model System is one of 14 model systems federally funded by the National Institute on Disability and Rehabilitation Research.

Dr Kristjan Ragnarsson

Dr Ragnarsson is Professor and Chairman of the Department of Rehabilitation Medicine and a long-standing proponent of FES (Ragnarsson, 1986, 1988, 1994, 2008; Ragnarsson et al. 1988). The FES program at Mt Sinai is conducted with Outpatients. It operates at a loss, but is considered very valuable and is therefore subsidized by other areas. The Ness H200 Hand Recovery System (http://www.bioness.com/bioness_hand_main.php) is used for FES of the hand. Dr Ragnarsson has investigated neuroendocrine changes following FES (Twist et al. 1992) and more recently has published on pain in spinal cord injury (Ragnarsson 1997, Bryce & Ragnarsson, 2000)

The main causes of spinal cord injury resulting in admissions to Mt Sinai are falls, work-related or sports-related injuries. One of the best features of the Mt Sinai Model System is the mentoring program, i.e. training of former patients to be mentors. A total of 60 former patients are now trained and assigned to patients to assist them during and after rehabilitation.

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Dr Jeanne Zanca

Jeanne is a Physical Therapist and Research Coordinator. Her role is to manage the Mt Sinai site for the study of outcomes following rehabilitation of spinal cord injury conducted by Susan Horn of the *Institute for Clinical Outcomes Research* (ICOR).

Dr Marcel Dijkers

Dr Dijkers is Associate Professor in the Department of Rehabilitation Medicine and is involved in the data collection required for the Model Systems. The Model Systems were set up because there was no organized expertise in the management of SCI in the mid 1970s. Mt Sinai sees less than 20% of SCIs in New York because of competition with other rehabilitation centres.

The national database contains no economic data as there is no comparison with state-based insurance (e.g. Blue Cross). Charge data have no relationship with actual costs, as every insurer negotiates the price of rehabilitation services and actual reimbursements, e.g. Blue Cross will reimburse $700 per day for 24 days, whereas Medicare pays a total of $20,000 for one admission. Therefore, Inpatient and Outpatient therapy are provided only until insurance benefits are exhausted.

The research being undertaken is predominantly observational. Data on aetiology, length of stay, complications, return to work have been examined so far. There are also other Model Systems in Traumatic Brain Injury (TBI) and Burns. The TBI Model System is better set up than SCI Model System. A panel chaired by Dr Ragnarsson will determine issues relating to Model Systems.

Susan Feldman Pollack

Susan Pollack is a Physical Therapist with expertise in the use of FES. She uses the *RT300 FES cycle* (Rehabilitation Technologies Inc). However the *Ergys 1* cycle is an earlier model and does not have a motor, therefore can provide a better idea of what patient can actually do. A case study has been published regarding the use of electrically stimulated muscle contraction to improve healing of a pressure ulcer (Pollack et al. 2004). A *NESS L300* Footdrop System and a *NESS H200 Hand Rehabilitation System* are also available (www.bioness.com).

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James Cesario

James Cesario is a former patient of the Mt Sinai Spinal Cord Rehabilitation Program. He runs the *Mentor Program*, which now includes 60 mentors. With the Recreational Therapists, he also coordinates the *Transition Program (Do-It!)* which runs from 9.30 am to 3.30 pm daily. The program comprises exercise, SW, counselling sessions including vocational counseling.

The *Do It!* Program is an outpatient program designed to facilitate community reintegration. These skills are taught by combining individual therapy sessions with informative group classes. Emphasis is placed on health promotion, wellness, and advocacy. Classes available for participants include Computer Education, Community Integration, Psychotherapy Group, Self-Enhancement Group, Technology Group, Weight Training Program, Wheelchair Mobility.

Kessler Spinal Cord Injury Research Center, New Jersey.

The Kessler Spinal Cord Injury Research Center is part of the Kessler Medical Rehabilitation Research and Education Center (KMRREC), established by the Henry H Kessler Foundation, a non-profit public charity. The Center is affiliated with the New Jersey Medical School and the Foundation also supports the rehabilitation of people with stroke and traumatic brain injury. There is a focus on research into bone, with Dr William Bauman heading the Metropolitan Bone Social Club Centre of Excellence at the Bronx VA – James A Peters Spinal Cord Research Center and a collaboration with Hologic (Thomas Beck). Studies have investigating the provision of Pamidronate in the acute period after SCI (Bauman et al. 2005).

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Dr Gail Forrest – Interim Director and Principal Investigator, Human Performance and Movement Analysis Laboratory

Gail is a graduate in maths/engineering from RMIT and completed a PhD in biomechanics at the University of Delaware. Her current project involves the investigation of the effectiveness of progressive locomotor training using BWSTT for incomplete SCI compared to a traditional overground walking training. Outcome measures include: muscle activity on and off the treadmill, autonomic function, bone density, muscle mass and metabolic function. Co-investigators include Susan Harkema, University of Louisville and Hugues Barbeau, McGill University, Montreal. This project is funded through the New Jersey Commission on Spinal Cord Research. Other research funding has been obtained through the Craig H Nielsen Foundation. Gail recommended exploration of robotic devices developed by *Kinea Design*, specifically the *KineAssist Robot* and the *Motor Recovery Measurement System* (http://www.kineadesign.com/portfolio/ . The co-founder is David A. Brown, Associate Professor in the Departments of Physical Therapy and Human Movement Sciences and in Physical Medicine and Rehabilitation at Northwestern University, Chicago.

Dr Anna Barrett – Neurologist and Director, Stroke Rehabilitation Research Laboratory

My discussion with Dr Barrett was concerned with upper limb recovery following stroke as well as alternatives to the RCT as a research design. She recommended some papers critical of the RCT (Tonelli & Callahan, 2001; Berguer, 2004), and others dealing with single cases (Beeson & Robey, 2004) and alternative analysis techniques such as multi-level models (Bingenheimer & Raudenbusch, 2006) and structural equation modelling.

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Dr Sue Ann Sisto, Research Scientist, Human Performance and Movement Analysis Laboratory

Sue Ann is also Associate Professor in the Department of Physical Medicine & Rehabilitation at the University of Medicine and Dentistry of New Jersey – New Jersey Medical School and Clinical Assistant Professor of Physical Therapy in the School of Allied Health Professions. Her current research involves use of the Smart Wheel for measurement of the biomechanics of wheelchair propulsion (Collinger et al. 2008; Price et al. 2007). Recommendations for injury prevention have been published (Boninger et al. 2005).

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Dr Peter Barrance, Research Scientist Rehabilitation Engineering Analysis Laboratory (REAL)

The Director of REAL is **Dr Thomas Edwards**. Dr Peter Barrance has investigated the loading of the knee during weight-bearing using a Fonar 0.6T WB MRI.

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Dr Stephen Kirshblum, Medical Director and Director, Spinal Cord Injury, Kessler Institute for Rehabilitation

Dr Kirshblum has recently published a series of papers on spinal cord injury management.

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Imperial College, Charing Cross Hospital, London

At Imperial College, I attended a seminar presented by Karen Bunday (PhD student of Dr Adolfo Bronstein – on the mechanisms involved in locomotor adaptation and after-effects (Bunday & Bronstein, 2008). I was also invited to give a seminar: *The motor control of trunk muscles.*

Reference

Bunday KL, Bronstein AM (2008) Visuo-vestibular influences on the moving platform locomotor aftereffect. *J Neurophysiol* 99(3):1354-65.

Prof Peter Ellaway

The purpose of my visit to Prof Ellaway was to discuss the neurophysiological testing regime that he had developed with funding from the International Spinal Research Trust.

Our discussion concerned the assessment of physiological motor outcome measures using Transcranial Magnetic Stimulation (Ellaway et al. 2004, 2007; Tranulis et al. 2006; Kuppaswamy et al. 2005; Stokes et al. 2005), the relative advantages of a cone coil versus a round coil for testing, sensory tests using a constant current stimulator (Davey et al. 2001, Savic et al. 2006, 2007). I observed the testing of a spinal cord-injured subject by Anna Kuppaswamy at the Spinal Unit at Stanmore.

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Spinal Injuries Unit, Brockley Hill, Stanmore

I was asked to repeat my seminar on the motor control of trunk muscles to the staff at Stanmore. I met with **Dr Fred Middleton** Consultant in Rehabilitation Medicine, **Prof Michael Craggs**, Director, Neuroprostheses Research Laboratory, **Zillah Bloomer**, Research Physiotherapist, **Dr Sarah Knight**, Engineer and Research Scientist, **Judith Susser**, Research Nurse and **Dr Vernie Balasubramanian** Physiologist. I did not meet with any clinical rehabilitation staff.

ASPIRE is a Spinal Cord Injury Charity (www.aspire.org.uk) emphasizing the reintegration and rehabilitation of people following spinal cord injury. One fundraising initiative is the coordination of a "Channel Swim". Volunteers register at the Stanmore pool and ask sponsors to fund them for swimming 22 miles. Funds are also obtained through bequests, sponsored walks and raffles. Funding from ASPIRE has assisted the establishment of an Exercise Centre that offers hydrotherapy, gym, Pilates, and Yoga. Volunteers assist with the Exercise Centre, which is also accessible to residents of the local community. A program of FES-rowing for community-based SCI people was set up by a former patient in the Exercise Centre.

The ASPIRE Chair in Disability and Technology is currently held by **Prof Martin Ferguson-Pell**, a Biomedical Engineer, at University College London and the Royal National Orthopaedic Hospital at Stanmore.

Research currently being conducted includes:

- Biomechanics of wheelchair propulsion relating to the risk of upper extremity over-use injury.
- Identification of pathological changes in tissues subjected to prolonged ischaemia using tissue reflectance and nuclear magnetic resonance spectroscopy (Bain & Ferguson-Pell, 2002; Lui et al. 2006a,b).
- Bone-related research by **Dr Ian McCarthy** using DXA, peripheral Quantitative Computer Tomography (pQCT) and Roentgen Stereophotogrammetric Analysis (RSA) to measure physical changes (bone density, bone thickness, loosening around an implant) mainly in general orthopaedics.
- The Neuroprostheses Research Laboratory has developed a rectal sphincter controlled via the dorsal penile nerve and has investigated somato-visceral reflexes following SCI (Craggs, 2006; Craggs et al. 2006)

References

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Swiss Paraplegia Centre, Nottwil, Switzerland

The Swiss Paraplegia Foundation (SPF), established in 1975 by Dr Guido Zäch, is unique in that it is supported by a large percentage of the Swiss population (1.2 million households) who are members of the Benefactors' Association that provides insurance in the case of spinal cord injury. The SPF operates the Swiss Paraplegia Centre (SPC) in Nottwil, the largest specialist spinal injury centre in Europe and provides a range of services such as purchase of aids, direct help for patients, car adaptation, as well as providing funds for research.

I was accommodated overnight in the striking Guido Zäch Institute on site (see left). My host was Helga Lechner. In terms of public relations, the SPC hosts 1000 visitors per week; these include families of inpatients at SPC, as well as classes of schoolchildren, or visitors from specific companies. Aspects of each program are illustrated by photographs along the corridors, so that visitors do not interrupt a Department's program. Members of the public regularly use the facilities in the SPC, including the pharmacy, restaurant, pool, and gym.

The SPC has 140 beds and manages around 160 newly injured patients per year. The Centre manages predominantly people with spinal cord injuries, but also has patients with ALS and Locked-In Syndrome. Length of stay can be up to 12 months by the time the house and car adaptations have been completed and work or training programs (re)established. *Parahelp* (nursing) will assist SCI people once they return home, but tries to build a relationship well before discharge. Follow-up is conducted at 3 months and 6 months, then yearly. Around 50 *Brindley* stimulators are implanted by the Urology Department per year as they have been found to work well, especially for women.

The SPC is extremely large and well-equipped. Both open/closed MRI and spinal CT are available. There is a helipad for emergencies, as well as operating theatres and a 6-bed ICU. In addition to the standard therapeutic programs (physiotherapy and occupational therapy), patients have access to speech therapy, advice on nutrition, acupuncture, music therapy, and Feldenkrais lessons, as well as hippotherapy (horse-riding) and companion dogs. A chiropractor works with outpatients. The SPC incorporates a paramedical training school (*Institut fűr Rettungsmedizin*), Pain Clinic and a Sports Medicine Clinic. In the evenings, patients have access to a range of different hobbies, including painting, under supervision.

The facilities are very impressive. The Centre is so vast that some administrative staff use scooters to manage the large distances between departments. In addition to the therapy departments, there is a large hall which can be divided into two areas. A new gym floor has been installed and the SPC now hosts the championships for wheelchair rugby. Other facilities include an archery room, woodwork centre, language centre, computer skills centre, and outstanding sports fields. Not surprisingly, the IT Department is quite large, with 20 staff. The SPC has its own radio and TV station with the radio transmitting continuously. On Monday evenings, a locally made TV program is transmitted.

A company called *Orthotec Nottwil AG* (http://www.paranet.ch/sw19904.asp) provides assistance with rehabilitation technology, wheelchair selection and modification as well as orthotic and prosthetic devices and incontinence products. Another company, *Rolli* (http://www.rollicompany.de/epages/Store.sf/?ObjectPath=/Shops/DemoShop) has adaptive clothing and other accessories for wheelchair users.

The SPC has been a leader in the development of assistive technology, with the mouth mouse and the tongue mouse developed at the Centre. The *Fondation Suisse pour les Télètheses (FST)* specializes in electronic aids and environmental control and works closely with the OT Department. Contact with employers is established as soon as possible after injury to check how the person's work can be modified or whether retraining needed. Language teachers are available to teach patients a new language and computer skills are also taught to enhance employability.

Physical therapy includes massage, baths, alternative therapies, colour therapies, reflexology, relaxation classes, and craniosacral therapy. Clinical sports teachers are part of the physiotherapy staff and encourage patients to join a sport groups and to learn different sports: skiing, paragliding, climbing.

In addition to the traditional treatment methods, the Physiotherapy Department offers Functional Electrical Stimulation (FES) and other electrotherapy-based treatments. Tomas Bűnzle, physiotherapist, took the time to explain these treatments. The FES team comprises a neurologist, rehabilitation consultant, physiotherapist, occupational therapist, and Director of Research. FES using the *MotionStim 8* stimulator is employed routinely in many applications:

- Abdominal muscles for coughing
- hand flexion/extension
- in ICU for reduction of shoulder subluxation
- walking

An *Automove AM 800* ® (Danmeter, Odense) is an EMG-triggered electrical stimulation device used to train upper limb function

The *Paresestim* is used for peripheral (cauda equina) lesions and stimulates muscle directly using a triangular pulse (the *Motionstim 8* uses asymmetrical biphasic waveform). It is important to monitor the number and strength of contractions and the use of stimulation. Pulses of 100 microseconds duration are applied every day for a maximum of 24 contractions, eventually decreasing to 50 microseconds. People with brachial plexus injuries use the *Paresestim* for one year, renting the machine. Good

compliance is essential for this demanding program. Krauth and Timmermann Flextrode Plus Art no 431, Size 4 oval electrodes are used. Larger sizes are used for the back, small ones for arm or face, and medium-sized electrodes for quadriceps. Electrodes have been found to last for two weeks, and can be washed in water after use. Stimulation is not used at all in demyelinating condtions such as Multiple Sclerosis or Guillain-Barré syndrome. The staff expressed the view that anti-spasmodic medication should be restricted because it inhibits regeneration. Both *Motionstim 8* and *Paresestim* machines are supplied by Medel (http://www.medel-hamburg.de/).

Trancutaneous Electrical Nerve Stimulation (TENS) is used in the treatment of decubitus ulcers Grade 2. Stimulation is applied around the lesion to obtain hyperaemia which leads to faster healing. Stimulation is used for 30 minutes daily, and for one hour if the skin condition permits. *TENS* (2 Hz) is also used after Botulinum toxin A injections. The stimulation is applied for 4 hours daily for 5 days to increase the uptake and therefore the effectiveness of Botulinum toxin A, especially when injected into the adductors, hamstrings, gastrocnemius/soleus, psoas, and hand muscles. Electrical stimulation at 2 Hz is also applied to strengthen weak muscles in incomplete SCI until the muscles are at Grade 3. Thereafter, strengthening exercises in the gym are employed.

The **Ergotherapy** (Occupational Therapy) Department is responsible for supply of wheelchairs. Patients are encouraged to try at least three different brands and decide for themselves as to which one they prefer. Patients are encouraged to attend the wheelchair workshop (see left) to learn how to service their wheelchairs and to ensure that they are safe for specific conditions (e.g. for winter conditions). There is a seating clinic with equipment (e.g. pressure mat) to determine seating pressure patterns. Appropriate support/seating systems are decided at meetings between an orthotist, physiotherapist, orthopaedic surgeon, and occupational therapist. The Department has links with architects and builders who specialize in home modifications and therefore have specific expertise in this field.

The Research Institute (Swiss Paraplegic Research) has facilities at the Guido Zäch Institute. A major project is the development of the International Classification of Functioning, Disability and Health (ICF) core set (Cieza et al. 2006; Stucki et al. 2008).

References

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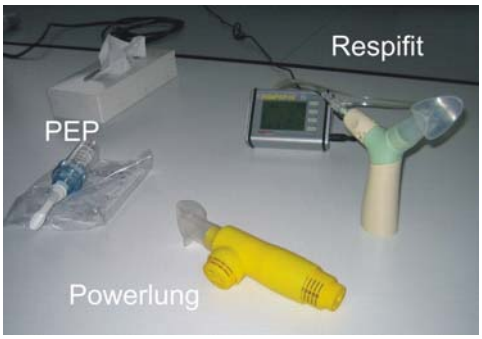
Cieza A, Geyh S, Chatterji S, Kostanjsek N, Ustun BT, Stucki G (2006) Identification of candidate categories of the International Classification of Functioning Disability and Health (ICF) for a Generic ICF Core Set based on regression modelling. *BMC Med Res Methodol* 6:36.

Other research projects are currently being undertaken:

Dr Gabi Müller (Research Scientist) is investigating the effect of respiratory muscle training in people with spinal cord injury. A cohort study conducted in eight rehabilitation centres in the Netherlands showed that respiratory function improves until the end of rehab and some improvement continues after discharge (Haisma et al. 2006). Dr Műller has investigated the optimal intensity for respiratory muscle endurance training in people with spinal cord injury (Mueller et al. 2006) and has also undertaken a prospective cohort study to investigate the time course for change in respiratory muscle function. She showed that expiratory muscle function remained weak (Mueller et al 2008a) and that training significantly improved respiratory muscle endurance (Mueller et al 2008b).

Devices for respiratory training include

1. *Positive Expiratory Pressure* at low resistance to train expiratory muscle strength. In inpatients it is used to train inspiratory muscle strength.
2. *Powerlung*: trains inspiratory and expiratory muscles especially the scalenes.
3. The *Respifit* (http://www.biegler.com/respifit_s.en.html) and *Spir-o-tiger* (http://www.spiro-tiger.com/html/main.html) are devices that have been developed for use by endurance athletes. Incentive spirometry can be used for training but is not considered effective. Patients take the device home and adjust minute ventilation to 60% for paraplegics and 40% for tetraplegics.



A new study of respiratory muscle training is being undertaken in chronic tetraplegics. Incentive spirometry is used as the control intervention. Fatigue of diaphragm is being measured using intraoesophageal electrodes with TMS to check central fatigue. Optoelectric plethysmography is being used to measure movement of thorax and abdomen (with and without abdominal binder).

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Mueller G, Perret C, Hopman MT (2008b) Effects of respiratory muscle endurance training on wheelchair racing performance in athletes with paraplegia: a pilot study. *Clin J Sport Med* 18(1):85-8.

Inge-Marie Velstra (Occupational Therapist) is coordinating a systematic review of arm and hand function and assessment tools for SCI, including the bionic glove (Balgrist). Members of the research team include Anne Sinnot (New Zealand), Jan Friden (Sweden), Anne Bryden (Cleveland), Johanna Wandel and Sue Sockfinder (Canada), Sandra Connelly (UK), Amin Kurt (Neurologist, Zurich).
Consensus on COPM.

Dr Antonia Coppin Phillips, a geriatrician is currently coordinating two cohort studies:

1. Public health follow-up of acute SCI patients over time, especially with regard to shoulder problems, pain, arthritis.
2. SCI and ageing: Swiss Paraplegia Centre, other Swiss centres, and community groups.
3. Nested projects include studies of cardiovascular function, bone parameters, biomedical factors (coordinated by Dr Ursula Graubman), environmental and personal factors, and arm and hand function

Grant applications have been submitted to the Swiss National Fund. The project is a collaboration between the Swiss Paraplegia Centre, Balgrist (Dr Huub van Hedel), Basel, and includes Traumatic Brain Injury.

Dr Stefan van Drongelen (Rehabilitation Engineer) is conducting projects concerned with shoulder function in people with spinal cord injury. His laboratory contains a *Qualisys Motion Analysis System* with high speed video cameras (500 Hz) and a treadmill suitable for wheelchairs. He is investigating shoulder loads in wheelchair patients during lifts and transfers and comparing these with loads generated by the hand cycle. The *Delft shoulder model* (http://mms.tudelft.nl/dsg/dutchsg/tud/shouldermodel.html) is being applied and inverse dynamics are being used to measure compression forces in joint and to model muscle function. A tripod of markers on the acromion (Meskers et al. 2007) is being used to measure the position of the scapula and the *SmartWheel* (Three Rivers USA http://www.3rivers.com/swhome.php) is used to measure forces on the wheelchair.

References

Meskers CG, van de Sande MA, de Groot JH (2007) Comparison between tripod and skin-fixed recording of scapular motion. *J Biomech* 40(4):941-6.

Van Andel CJ, Wolterbeek N, Doorenbosch CA, Veeger DH, Harlaar J (2008) Complete 3D kinematics of upper extremity functional tasks. *Gait Posture* 27(1):120-7.

Angela Frotzler (Physiotherapist) has conducted studies on bone loss after spinal cord injury. Although there is emphasis on measures of the inorganic part of bone (calcium), it is also important to examine the organic components. Seventy percent of bone loss is in spongy bone. There is a wide variation in fracture threshold. Bone mineral density (BMD) itself is insufficient to determine whether a fracture will occur. Peripheral quantitative computed tomography (pQCT) is used to measure bone shape and geometric distribution, but the strength/strain index and cortical thickness help in estimating fracture risk. Bone status is independent of age (and hormones) in SCI. It is the lack of mechanical loading that is the critical factor

There is evidence that FES cycling increases bone density and leads to a reduced rate of bone loss, but this depends on the intensity of training. A collaborative study has been undertaken between the Swiss Paraplegia Centre in Nottwil and the Queen Elizabeth National Spinal Injuries Unit in Glasgow (Frotzler et al. 2008). Eleven patients with complete SCI cycled 5 times per week for 12 months on their highest power output. There was an increase in BMD of 25-50% in trabecular area Within 6 months, the effect faded and after 12 months there was a detraining effect so that only 60% of the effect was observed. This has been interpreted in terms of the effect being maintained without training. Two participants continued training twice per week for 30 minutes and maintained the gain in BMD.

Training programs are needed to prevent bone loss following SCI. Physicians and patients need to be informed about bone studies. A recent case report (Dudley-Javoroski and Shields, 2008) showed that a unilateral soleus muscle stimulation protocol performed over a period of four years halved the rate of decline in tibial BMD.

References

Dudley-Javoroski S, Shields RK (2008) Dose estimation and surveillance of mechanical loading interventions for bone loss after spinal cord injury. *Phys Ther* 88(3):387-96.

Frotzler A, Coupaud S, Perret C, Kakebeeke TH, Hunt KJ, Donaldson ND, Eser P (2008) High-volume FES-cycling partially reverses bone loss in people with chronic spinal cord injury. *Bone* Mar 20. [Epub ahead of print]

Kakebeeke TH, Hofer PJ, Frotzler A, Lechner HE, Hunt KJ, Perret C (2008) Training and detraining of a tetraplegic subject: high-volume FES cycle training. *Am J Phys Med Rehabil* 87(1):56-64.

Balgrist University Hospital, Zűrich, Switzerland

Professor Volker Dietz is the Director of the Uniklinik at Balgrist. My host was Dr Huub van der Hedel, Physiotherapist and Head of Research (http://www.balgrist.ch/index.cfm/s_page/58190). I was invited to give a seminar on my work on regeneration following spinal cord injury in mice.

The hospital at Balgrist commenced as an orthopaedic centre for management of scoliosis. In 1990, 46 additional beds were dedicated to the management of spinal cord injury. Thirty-eight of these beds are currently occupied.

Balgrist is the coordinating centre for the European Multicenter Study about Spinal Cord Injury (EM-SCI; http://www.emsci.org/). This project will examine natural recovery from SCI over time, with assessments conducted in the acute phase, then at 4 weeks, 3 months, 6 months and 12 months. It involves 17 European Centres in Switzerland, Germany, France, Spain, Netherlands, Italy, and the Czech Republic. Standardized outcome measures include the ASIA, SCIM, WISCI, timed tests (TUG, 10 m walk, 6 min walk), walking at natural and fast speeds, neurophysiology (somatosensory and motor evoked potentials, nerve conduction studies, latencies, amplitudes). In addition, a structured interview re types of pain is conducted.

Other staff I met were:

Mr Markus Wirz, Head of Physiotherapy. The Physiotherapy Department has a *Lokomat* (http://www.hocoma.ch/web/en/products/prd_lokomat.html) which is used for patients with incomplete SCI. There is an indoor rock climbing wall (left) in a corner of the gym to challenge the balance, strength and control of patients with incomplete injuries. There are two hydrotherapy pools, a small pool maintained at a warmer temperature and used for individual treatments, and a larger pool used for swimming. All patients are taught to swim where possible as part of their rehabilitation.

Susan Wydenkeller is a PhD student investigating neuropathic pain in people with SCI. She is using heat evoked potentials to obtain pain thresholds, and to attempt to provoke wind-up pain. A 32 channel EEG is used to measure any changes in frequency associated with the stimulation. Subjects also rate their after-sensation. The underlying rationale is that thalamocortical dysrhythmia is associated with frequency shifts in the raw EEG. The stimulus, unlike laser stimulation, produces quick heat, like a pinprick. Subjects with SCI are tested above the lesion, at the level of the lesion, in the zone of partial preservation, and 3 segments below the lesion. The back is used for testing because the responses are more reliable and can be standardized. On the back, the sensory nerves are relatively short and the perception distance is constant, unlike the front of the body where the location of the stimuli might be altered due to differences in abdominal girth etc. The conduction

velocity in the spinothalamic tract is ~11.2 m/sec. The Cz electrode (over the vertex) records NP potentials. Laser heat pulses are short but produce a prolonged stimulus, and the laser cannot be used to produce cold stimuli. The equipment used to produce heat-evoked potentials can also produce cold stimuli. The research has so far not yielded any specific insights into neuropathic pain; however, a longitudinal study is planned, with patients measured at 1 month, 6 months, 12 months. It is expected that neuropathic pain would appear within 6 months of injury. The response to the heat stimuli might be of predictive value.

Reference

Wydenkeller S, Wirz R, Halder P (2008) Spinothalamic tract conduction velocity estimated using contact heat evoked potentials: what needs to be considered. *Clin Neurophysiol* 119(4):812-21.

Dr Mark Bolliger has been involved in further development of the *Lokomat*, a robotic device used to provide locomotor training. The most recent experimental versions of the machine have included control of hip ab/adduction and also provide assistance with translation of the pelvis from side to side. While these are welcome developments, it has increased the complexity and weight of the machine. It is not envisaged that this level of control would be available in clinical machines in future, but will remain experimental. The advantage of the *Lokomat* is that it can be used in very early SCI patients. It can be programmed in biofeedback mode, so that forces exerted by the patient can be sensed by the machine, and assistance provided as necessary, from 100% to very little assistance. This works well for control of the hip joint motion, and similar assistance could be provided for stance control for the knee joint in the near future. From work done on a *Lokomat* for rats which had a "puff-control" mode, the equipment will also include a window where the timing of an action will be left open for the patient to control the final foot position. The robot will kick in when the patient approaches the correct position. The *Lokomat* comes in basic and Pro versions. Chafing of the cuffs on the legs can be a problem and silk-lined cuffs have been developed to reduce the amount of friction.

Jan Michel is a PhD student from Jena University in Germany, who is studying motor control during obstacle negotiation. An elaborate experimental setup has been developed. A treadmill with force plates underneath also has a mechanism which permits an obstacle (constant height) to arise at certain intervals. An infrared sensor measures foot clearance. Some trials have an acoustic warning signal regarding the appearance of the obstacle, while others do not. The frequency of the tones indicates a higher frequency of appearance of the obstacle. In some situations patients wear goggles which obscure the lower half of the visual field. The experiments have been designed to investigate the reflexes involved in the task (Michel et al. 2008). In another area of the laboratory, a force plate was inserted into a pool, and patients immersed, but supported by a harness. Responses to forward, backward, sideway perturbations of the force plate were able to be recorded without gravity as a factor.

Reference

Michel J, van Hedel HJ, Dietz V (2008) Obstacle stepping involves spinal anticipatory activity associated with quadrupedal limb coordination. *Eur J Neurosci* 27(7):1867-75.

Dr Tobias Nef has just completed his PhD investigating an arm robot called *ARMin*, developed by Dr Robert Riener, a Rehabilitation Engineer at the Swiss Federal Institute of Technology, Zűrich (ETH) (http://www.sms.mavt.ethz.ch/research/projects/armin/therapy).

The robot is designed to allow performance of natural movements, unlike the *Manus* robot developed at the Massachusetts Institute of Technology. At first, the patient's arm is taken through a range of movement at shoulder, elbow and wrist, so that the robot "learns" the movement. The robot is then programmed to carry out this passive movement for a period prior to the commencement of the exercise program, permitting release of any spasticity. Various games are available, the simplest being a catching task, with a bouncing ball needing to be "caught" by a block which needs to be moved from side to side. The task can be made more difficult by increasing the speed and range of movement, and the precision with which the ball needs to make contact with a certain region of the block. Other games include table tennis, movement in a grid, and activities such as lifting objects onto shelves etc. The robot allows movement laterally but also against gravity. A unique feature of the robot is the allowance for elevation of the shoulder girdle, permitting a more natural movement of the shoulder during flexion and abduction of the arm (Nef et al. 2007).

Reference

Nef T, Mihelj M, Riener R (2007) ARMin: a robot for patient-cooperative arm therapy. *Med Biol Eng Comput* 45(9):887-900

Claudia Rudhe-Link is the Head of Ergotherapie (Occupational Therapy), and is also a part-time researcher in the spinal injury research centre. She worked for a time in Melbourne at the Hampton Rehabilitation Hospital. Occupational therapists at Balgrist are responsible for all rehabilitation of the hand, as well as provision of wheelchairs, seating, wheelchair training and assistive technology. Included on staff are a person who teaches computer skills to patients, and a person responsible for contacting employers regarding employment and training. There is a workshop where wheelchairs can be assembled, and serviced. Patients are often encouraged to undertake this service themselves in order to give them experience, as well as to provide them with standing endurance. As part of the EMSCI collaboration, Claudia has been collaborating with a number of centres, including Toronto, regarding the SCIM. An important project is the development of the GRASP instrument, in collaboration with centres in Europe, USA and Canada. A poster will be presented at the next ASIA meeting.

Mark Lawrence is a physicist currently completing his PhD in the area of FES under the supervision of Thierry Keller. This group has used electrode arrays rather than the standard self-adhesive electrodes (Keller et al. 2006). The latest work from the group was reported at the FES conference in Vienna and will be published in *Artificial Organs*

in 2008. The electrodes are silver threads woven in 1cm square blocks in a lightweight lycra fabric. This is done in St Gallen in Switzerland. The electrodes are then connected to a controller using standard ribbon cables. The electrode array permits very precise control of each of the fingers. Although smaller electrodes can be used, in practice the current would then be concentrated in too small an area and could lead to skin irritation and burns. The material can be washed about 30 times before it needs to be replaced. Hydrogel is used as the interface medium. A new medium and a new controller are currently under development and details cannot be made public as yet. A commercially available product should be available within a year.

Compex, the company set up by Thierry Keller, produces a 4-channel stimulator used in sports and fitness programs to help athletes recover from injury by strengthening muscles without needing to specifically train the injured part. These stimulators have a fixed set of ten programs available and cost between 700-1,000 Euros. They are available in Australia ((http://www.compexaustralia.com.au/). The M1 series has an accelerometer which will automatically detect motor threshold. Another stimulator is under development, which will permit changes in pulse width, stimulus frequency, ramping up and down. It will be available for research only and will cost around 5,000 Euros. EMG feedback will permit detection of activity, e.g. of the shoulder, as a trigger for hand opening or closing.

Reference

Keller T, Lawrence M, Kuhn A, Morari M (2006) New multi-channel transcutaneous electrical stimulation technology for rehabilitation. *Conf Proc IEEE Eng Med Biol Soc* 1:194-7