PREVENTION. CARE. RECOVERY.

Intensive Exercise Programmes for Spinal-Cord-Injured Individuals

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Important Note:

This evidence based review summarises information on intensive exercise programmes for spinal cord injuries and provides best practice advice. It is not intended to replace clinical judgement, or be used as a clinical protocol. A reasonable attempt has been made to find and review papers relevant to the focus of this report. It does not claim to be exhaustive. This document has been prepared by staff of the ACC, Evidence Based Healthcare Team, Research Services. The content does not necessarily represent the official view of ACC or represent ACC policy.

Executive summary

Background

ACC currently receives requests from clients with spinal cord injuries to fund intensive semi-residential/outpatient exercise programmes following their discharge from post-acute rehabilitation. It was, therefore, appropriate for ACC to review the evidence for the safety and efficacy of such programmes – this includes reporting on the safety and efficacy of any individual therapeutic modalities that may be used in combination in these programmes.

Search Strategy

Relevant medical databases and an extended internet search were undertaken to identify human clinical trials trialling exercise therapy interventions in a sub-acute and chronic spinal-cord-injured population (1966-August 2007).

Main results

Distinct Neuro-rehabilitative or integrated exercise programmes

Six distinct programmes (Massed Practice Therapy"/ (aka Constraint Induced Therapy) "Activity Based Programming" "Coordinated Dynamic Therapy" "Project Walk" (The Dardzinski Method) "Reactivate" and "Beyond Therapy Programme" (Rehabilitation Institute of Michigan)) underpinned by one or multiple specific neuro-rehabilitative philosophies and/or exercise programmes were identified. Specific programme components and overall programme, frequency, intensity and duration are all customised to the individual based on their level of function and ability as identified from lengthy assessment processes. Published literature supporting these programmes consisted of one randomised controlled trial (RCT) and three case studies that related to three separate programmes. The RCT was the only study that met the inclusion criteria for this report. The RCT compared the outcomes from Massed Practice Therapy (MP) and MP and somatosensory stimulation (SS). The findings indicated small improvements in hand function scores in the MP + SS group. The paper, however, was of low quality, with non-blinded assessment, and lacked information regarding randomisation and concealment allocation. No conclusion can be made, therefore, about outcomes as compared with traditional therapy and thus overall safety and efficacy of this particular intervention strategy.

Individual Therapeutic Modalities

Most of the programmes identified above consisted of a number of combined specific therapeutic modalities with conventional exercise regimes. Those reviewed for this study were: neuromuscular electrical stimulation (NMS), electromyographic (EMG) biofeedback and body-weight-supported treadmill training (BWSTT).

Body-weight-supported treadmill training - BWSTT

Three randomised controlled trials (RCT's), one non-randomised comparative study (two publications) and eight case series reported efficacy outcomes following BWSTT. The studies were consistent in reporting improvements in impairment parameters and function from baseline to varying follow-up time points (4 weeks-12 months) following treatment. Overall, however, the evidence for treatment efficacy is weak due to small samples and poor methodology and reporting. Significant heterogeneity existed across the studies in terms of populations enrolled and intervention parameters delivered; many studies also administered concurrent treatments. One small case series only specifically reported evidence of pathological knee findings following BWSTT and one other trial only reported adverse events following treatment.

In summary, there is weak positive evidence for the use of BWSTT for the post-acute phase after spinal cord injury. There is, however, insufficient evidence currently to conclude this is a safe intervention due to the lack of information from the trials to date.

Neuromuscular electrical stimulation (NMS)

Three RCT's, 10 case series and one case study reported outcomes from three types of NMS interventions; Functional Electrical Stimulation (FES), Patterned electrical stimulation (PES) and Transcutaneous Electrical Stimulation (TENS). Three case series involved FES ambulatory systems specifically. The majority of the papers reporting on FES are for standing/walking. All studies consistently reported positive outcomes in terms of reduction in spasticity, and/or improvements in walking parameters. Functional outcomes were, however, reported in a few papers only, and only one of these employed a valid and reliable measure of function. The quality of these papers was also poor and the samples small and populations heterogeneous. One case report and one case series addressing safety specifically were identified and three further case series reported adverse events. Adverse events included significant complications or harm; these ranged from surface burns from electrode skin contact to bone microfracture (FES cycling) and fractures from falls (Parastep ambulation system).

In summary, there is weak positive evidence to support the efficacy of a variety of NMS interventions in the sub-acute and chronic spinal cord population. There is insufficient evidence currently to conclude this is a safe intervention due to the lack of information from the trials to date.

EMG Biofeedback

One randomised controlled trial was reviewed which concluded EMG biofeedback when compared with a standard rehabilitation programme produced similar outcomes. The quality of this study was poor. There is, therefore, insufficient

evidence to support the safety and efficacy of biofeedback in the sub-acute and chronic spinal cord population.

Conclusions

There is currently insufficient literature regarding specific intensive exercise programmes for the management of individuals with spinal cord injury in the post-acute and chronic phase following injury. No conclusions therefore can be made regarding the safety and efficacy of these programmes.
There is, however, some published evidence relating to the use of BWSTT, EMG biofeedback and NMS which are components of many of the programmes. This evidence appears consistently positive for BWSTT and NMS interventions, however, it is of very poor quality. Two case series only report on safety specifically with BWSTT and FES. Adverse events are poorly reported across all three modalities. There is currently, therefore, weak evidence for efficacy only of BWSTT and NMS. There is insufficient evidence to state the efficacy and safety of biofeedback in this population due to the paucity of literature.

Acknowledgements

Glossary

Closed kinetic chain exercise: are exercises performed in which the peripheral limb (hand or leg) is fixed and cannot move e.g. squat, leg press. The purported advantages of these exercises are that they are compressive exercises and, therefore, do not involve shear forces; they also work multiple muscles simultaneously[1].

Electromyography: (EMG) is a technique for evaluating and recording the physiologic properties of muscles at rest and while contracting[2].40

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1. Background

ACC currently funds post-acute spinal cord injury rehabilitation via the two Spinal Injury Units (Auckland and Burwood Spinal Units in Auckland and Christchurch respectively). This contractual arrangement allows up to 80 days of inpatient rehabilitation. ACC funds follow-up assessments and management after initial discharge via both these units. Follow-up assessments are initially completed within six months, and thereafter at least annually. In some instances following inpatient discharge, clients (if local to the spinal unit) may be wait-listed for outpatient therapy at the spinal unit; in general though, spinal unit staffing levels mean that clients who are identified as needing ongoing rehabilitation source this from a private provider.
There appear to be a small number of non-contracted providers of these services within New Zealand who offer intensive exercise programmes to clients with spinal cord injury. Clients either self-refer to these programmes or are referred by their ACC Client Services staff.

Community-based ongoing rehabilitation is usually provided via the ACC funded 'Training for Independence' contracts. Furthermore, ACC has recently established its National Serious Injury Service nationwide. This service aims to deliver better client outcomes and is aligned with the social integration model.

From time to time ACC receives requests from both clients and providers to fund courses of intensive semi-residential/outpatient exercise rehabilitation following discharge from the spinal unit.

Traditionally, exercise therapy for clients with spinal cord injury in New Zealand has been delivered primarily by Physiotherapists, and to a lesser extent Occupational Therapists. Therapy has included overground walking – assisted by devices and/or manual therapist assistance; functional exercises; strengthening and stretching activities. Therapeutic interventions aim to activate the paralysed muscles, strengthen the weak musculature and mitigate the effects of spasticity with the carry-over into functional activities, such as walking and feeding.

Some of the programmes and/or individual modalities identified in this report are administered by Exercise Science trained clinicians (e.g. Project Walk, "Reactivate"). This may have implications for both clients and purchasers of rehabilitation services in New Zealand as these clinicians are not included in the Health Practitioners' Competence Assurance Act 2003[3].

This report takes into consideration two previous EBH reports (1) Project Walk" (2004) – an intensive exercise programme designed for spinal-cord injured individuals and (2) ERGYS (2005) - a commercially available FES cycle ergometer.

2. Objectives

The aim of this report is to review the evidence for the safety and efficacy of intensive exercise programmes available for spinal-cord-injured individuals (local and international) after having gone through their post-acute treatment phase (>80 days post-injury).

3. Methodology

3.1 Criteria for selecting studies for this review

Types of Studies

Clinical trials in English that reported functional, ambulatory and/or safety outcomes with intensive exercise programmes. For the purposes of this report, "intensive" is classified as any exercise intervention(s) requiring an individual's participation two hours or more per day, for most days per week, for a number of weeks. Any follow-up or home programme following an initial outpatient or semi-residential programme was also evaluated if reported.

Types of participants

Human spinal cord-injured patients of all ages, male and female, with complete or incomplete injuries at any spinal level in the 'post-acute' (classified for this review as >80 days post injury) phase following injury.

Exclusions

Studies reporting outcomes from interventions aimed at mitigating secondary complications or impairments following spinal cord-injury (e.g. cardiovascular disease risk reduction, plasma insulin levels, lipid profiles, pressure sore prevention, impaired sexual or bladder function or respiratory function) were excluded.

Therapies based on device implantation (e.g. FES implants) were also excluded from review.

Case reports were excluded unless they reported specifically on safety. Case series with fewer than 10 participants were excluded from review.

3.2 Search Strategy and Information Sources

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The following medical and scientific databases were searched. The search strategy is detailed in Appendix 1.

AMED
Cinahl
Cochrane Central Register of Controlled Trials
Current Contents
Embase
Medline
Index New Zealand
Science Citation Index

Review databases
ACP Journal Club
Cochrane Database of Systematic Reviews
Database of Abstracts of Reviews of Effects
NHS Economic Evaluation Database
Health Technology Assessment Database
TRIP database

An extended Internet search was also performed.

3.3 Methods of the review

1. The type of study was determined by analysing the methodological information described in each report.

2. For controlled studies the quality of study design was assessed by analysing the information including the methods of randomisation or blinding, sample size, outcome measurements, period of follow-up, definition of study population and intervention, criteria of inclusion and exclusion and potential bias in the study.

3. The levels of evidence were determined by considering both the type of study and the quality of study design for controlled studies according to an international standard.

4. Evidence tables summarise the information on study type, clinical conditions, study population, intervention, outcomes and the level of evidence determined.

All literature was subsequently appraised using the Scottish Intercollegiate Guidelines Network (SIGN) literature grading criteria (Appendix 2).

4. Results

Over 3000 abstracts were initially identified from literature searching.   After excluding non-English and papers distant to the scope, 1804 abstracts were reviewed. One hundred and forty-five publications were retrieved for full text review.

A comprehensive publication collating published evidence on the rehabilitation strategies and community-based programmes for spinal cord injuries (Spinal Cord Injury Rehabilitation Evidence (SCIRE(2005[4])) was also identified from the literature search. This was published collaboratively by the International Collaboration on Repair Discoveries, University of British Columbia, Canada (ICORD) and a number of other clinical and academic groups working in the field of spinal cord injuries. This document provided useful background information and also served as a cross-referencing tool to ensure all relevant literature had been identified.
Of note also, in the United States, the Neurorecovery Network (NRN) is a cooperative network of treatment and rehabilitation providers (currently seven centres involved), funded by the Dana and Christopher Reeve Foundation. These centres promote an evidence-based approach to the research and treatment of spinal cord injured individuals. Currently patients only with incomplete cervical and thoracic lesions are able to access these treatment centres[5].

A substantial volume of literature reports on the use of specific therapeutic modalities to *mitigate secondary complications* from spinal cord injury (e.g. bone mineral density loss, atherosclerotic profile, pressure sores from insensate skin). These papers were outside the scope of the project, and thus excluded from review.

Six distinctive neuro-rehabilitative strategies and/or physical exercise programmes were identified from both the systematic literature search and wider web searches; these are as follows:

- "Massed Practice Therapy"/ (aka Constraint Induced Therapy[6])
- "Activity Based Programming"
- "Coordinated Dynamic Therapy"
- "Project Walk" (The Dardzinski Method)
- "Reactivate"
- "Beyond Therapy Programme" (Rehabilitation Institute of Michigan).

One randomised controlled trial (RCT), one case series two case studies only related to the efficacy of the six programmes. The case series and case

studies did not meet the report inclusion criteria, however, a brief description on the theoretical approach and rehabilitation involved is provided.

Thirty-five additional publications were identified that reported on the modalities that many of these programmes offered in combination. These individual modalities are presented under three main modalities, that of Body-weight supported treadmill training (BWSTT) and Neuromuscular Stimulation (NMS) and Electromyographic (EMG) biofeedback.

No publications reported on interventions with children with spinal cord injury. Table 1 summarises the literature identified for this review. Study tables of the reviewed papers are provided in Appendix 3. Additional information on health technology is provided in the specific results sections.

Table 1: Summary table – literature meeting the project brief

SPECIFIC THERAPEUTIC MODALITIES	SYSTEMATIC REVIEWS	RANDOMISED CONTROLLED TRIALS	NON-RANDOMISED COMPARATIVE STUDIES	CASE SERIES	CASE REPORTS
Body-weight-supported treadmill training		3	1#	8	
Neuromuscular Electrical Stimulation		2*		10	1
Biofeedback		2♣			
Other (including strengthening regimes and other multi-modality standard intervention programmes)			1	2	
"Massed Practice Therapy"		1			
"Activity Based Programmes"					2
"Coordinated Dynamic Therapy"				1	
"Project Walk"					
"Reactivate"					
"Beyond Therapy Programme"					

*=both RCT's are quasi-randomised; ♣ = one RCT involved EMG biofeedback in two of the four trial arms (Klose et al.1990[7]), the second RCT trialled EMG biofeedback concurrently with exercise therapy and NMS (Klose et al. 1993[8]); # = two publications report short and longer-term follow-up on similar study cohorts (Wernig et al. 1995[9] and 1998[10]).

Massed Practice (MP) Therapy

Massed Practice therapy (formerly/also known as Constraint induced therapy[6]) involves the repetitive practice of specific movement or functional tasks by the affected limb (predominantly the upper limb). In the case of spinal cord injuries it is usual for all limbs to be affected, albeit unequally. Massed Practice Therapy would be tailored to one limb based on a therapist's assessment of the individual. The authors of the single paper reviewed for this report stated:

> Studies that have demonstrated that the factor underlying
> the difference in outcomes associated with constrained
> induced therapy and traditional therapy is not constraint of
> the uninvolved limb, but the required frequency of use of the
> involved limb. Therefore the term "massed practice" is the
> more appropriate term to describe an intervention in which
> repetitive practice is the primary therapeutic factor[6].

The RCT involved 10 subjects and investigated the effect of Massed Practice therapy (MP) combined with somatosensory stimulation (SS). Subjects were randomised into an MP or MP + SS group (median nerve stimulation at wrist). Although the trial met the project brief this paper was written on the premise that MP therapy had been effective in a stroke population (three papers). Statistically significant improvements in Jebsen Hand Function test scores and some other measures was in favour of the MP + SS group ($p < 0.05$). The small sample size, however, and the nature of the control group mean the study adds little to the evidence for effectiveness per se of MP therapy compared with traditional interventions. Furthermore, the paper was of low quality, with non-blinded assessment, and a lack of information regarding randomisation and concealment allocation. This reflects the assigned SIGN grading of 1-.

Coordinated Dynamic Therapy (CDT)

With central nervous system damage, the firing frequency of neuronal networks and neuronal network integration is disrupted. CDT purports that performing repetitive rhythmical upper and lower body cyclical motions may recreate/restore the damaged/non-functioning neuronal connections. This therapy is underpinned by the existence of 'central pattern generators'; groups of neuronal cells and networks within the spinal cord which allow muscles to be activated in specific synergistic patterns[11]. CDT therapeutic activities include repetitive crawling, creeping and walking. The developer of this therapeutic approach is Professor Giselher Schalow of Estonia. Specialised equipment has been developed for this therapy (Giger MD®) that allows cyclical upper and lower body activities e.g. supine arm and leg cycling - both active and passive options. Equipment includes the GIGER® MD Locomotion System - a supine arm/leg cycling device and the GIGER MD® Therapy Instrument Booster Impulse - a reciprocal stepper device[12]. Computer

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software and biofeedback can be used with the equipment to record motor outputs. Treatment frequency is 4-5 hours per day, for 3 months.

Two case reports were identified that reported on the use of this therapy with spinal cord-injured individuals[11][13]; both were excluded from formal review as they involved <10 subjects and related to the acute-post-injury period.

"Activity Based Recovery Therapy /Programming"[14]/Restoration therapies[15]

"Activity based recovery therapy" involves the patient performing reciprocal 'gait-like' movements using a seated cycle with concurrent FES. This is similar to CDT in that it aims to engage the body's 'central pattern generators' [16] in response to sensory input to the spinal cord. It is theorised that activating the central pattern generators may also modulate spasticity[16]. Other secondary aims of Activity Based Recovery Therapy are to minimise secondary complications from immobility and to improve muscular and cardiovascular fitness[15].

Other components of the programme include BWSTT (including Lokomat®, robotic walking and 'aquatherapy'). The rehabilitation centre in which the therapy developer currently works offers other interventions for the injured patient including peripheral nerve transfers and nerve reconstruction for brachial and lumbosacral plexus repair and FES implants for hand and bladder function.

A single case study reported improvements using this therapy in one individual five years after a complete high cervical cord injury. In this case, training was one hour per day, three times per week. FES cycling was also supplemented with surface electrical stimulation to various muscle groups (trunk, upper and lower body), 30 minutes/session.

"Beyond Therapy" (Rehabilitation Institute of Michigan) – Centre for Spinal Cord Injury (CSCI®)

The CSCI® describe their programme as a long-term, high-intensity, non-traditional activity-based therapy program that utilizes innovative exercise techniques to optimize recovery[17]. Clients must have already undergone a 'traditional rehabilitation programme' to be eligible to enter the programme. Information gained from the CSCI web-site indicates the primary aim is for recovery not adaptation, and their programme is stated as "activity-based". There is no information available to indicate that this rehabilitation programme purports to follow a specific therapeutic strategy or philosophy. That said, patients use the Giger MD® and specifically perform closed kinetic chain activities. No information is available to indicate other treatment modalities. The programme is for three hours per day, five days per week. Of note, Whole Body Vibration is a key intervention, with purported benefits of improved muscle strength, flexibility, range of motion and circulation. No

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published literature was identified reporting outcomes from the Beyond Therapy programme. No other information regarding programme costs or outcomes from the programme was available despite attempts to contact the Rehabilitation Institute.

A report in preparation by the ACC Evidence-based health team reporting on the safety and efficacy of Whole-body Vibration Training for healthy and rehabilitation populations is almost complete. This report may inform the discussion regarding treatment modalities and exercise programmes for spinal cord-injured individuals.

Project Walk®

Project Walk® is an intensive exercise programme designed specifically for individuals with spinal cord injury. It uses an approach known as the Dardzinski Method™ and was established by Ted and Tammy Dardzinski in Carlsbad, California in March 1999. Project Walk entails a residential programme based in San Diego and also offers a home-based rehabilitation programme for clients that are unable to travel to San Diego. Each client undergoes a week-long evaluation process on arrival to the centre to identify their needs. Time commitment for low cervical and high tetraplegics is reported as 3 hours every second day and programmes are set according to their needs as identified from their assessment. Clients are re-evaluated monthly thereafter. The philosophy of Project Walk® is to actively encourage the client's muscle spasms in their affected limbs and create new spasms either by movement or generating stretch reflexes. There are five phases of recovery which require different therapeutic approaches:

- Phase I: reactivation
- Phase II: development and stabilisation
- Phase III: progress eccentric and concentric muscle contractions
- Phase IV: function and coordination
- Phase V: gait training

The aim is to generate and increase neural activity which may initially be uncontrolled by resisting muscle spasm. The client is then trained to apply force through the resistance. The final phase of the programme is balance and gait training which begins once stabilisation of joints starts to occur, and involves treadmill and exercise bike work. The programme continues until the client is satisfied with their progress but a suggested time frame of "two years plus" has been cited.
No published literature was identified that reported outcomes following use of this programme either for the 2004 brief report, or for this update. Costs of this programme are US $100 per hour with a package price for training further therapists to manage clients independently (1 week, US$2,350.00).
The brief report by the ACC EBH team in 2004 identified that a New Zealand "chapter" of Project Walk™ had been established in a New Zealand fitness centre (Bruce's Gym, Te Awamutu) in 2003[18]. An e-mail from Bruce's Gym (received October 2007) indicated that the rehabilitation programme offered to

spinal-cord-injured clients was no longer affiliated with Project Walk (see "Reactivate" below).

New Zealand Providers - rehabilitation programmes available to spinal-cord-injured clients

Reactivate™

Reactivate™ is the company name for a Te Awamutu provider of rehabilitation to post-acute and chronic spinal cord-injured clients.   Reactivate™ rehabilitation programme has been available to people with spinal cord injuries since October 2004. Patients can self-refer or be referred to the service and require medical clearance in order to attend. The programme's initial focus is on the development of core abdominal stability[19] and the developers also describe it as holistic, using closed kinetic chain activities with attention to flexibility. A variety of modalities are used and the programme is tailored to the individual; modalities include: Functional electrical stimulation (FES), weight bearing treadmill work, standing/gait training using parallel bars and manual cycling/grinder[20]. The cost for this service is $180 per day, with accommodation available at additional cost. Assessment of the new client takes place over two weeks (20 hrs). Mutually agreed goals are then developed and the programme engages the client 2 hrs (one-on-one) daily, 4-5 x per week. There is no specified programme length. Nutrition and general health advice are also incorporated into the programme. Patients are re-assessed either at 12-week or 6-month intervals. A home programme may be appropriate; this requires the client to attend for a minimum 4 weeks initially and return every 6 weeks for one week of daily treatment. Patients currently self-fund their treatment to Reactivate™.

Other Providers

Anecdotally there are a number of additional private rehabilitation providers in both the North and South Island. No information identified through general web-based searching indicated these providers adhered to specific rehabilitation philosophies or regimens. One example of such a provider is Neurorehab Results in Auckland. Modalities used include FES, BWSTT, strength training, functional retraining, caliper and overground gait retraining[21].

Summary

The evidence is unclear to support the safety and efficacy of integrated intensive exercise programmes currently available. This is based on one RCT and three case reports for three programmes that report on programmes not available in New Zealand. One New Zealand provider (Bruce's Gym) currently offers semi-residential programmes for spinal cord injured clients. No data or published literature is currently available to assess its efficacy and safety.

Individual therapeutic modalities

The specific therapeutic modalities/interventions that are reported in the identified programmes (delivered in isolation or combination) are as follows:

- **Body-weight-supported treadmill training (BWSTT[⊕]):** Two randomised controlled trials (RCT's), one non-randomised comparative study (two publications) and eight case series were reviewed. Some published trials combined BWSTT with other modalities or equipment e.g. FES, robotic gait-driven orthoses (Lokomat®).

  One RCT (two publications) was excluded from review as it assessed the effect of BWSTT in spinal cord-injured individuals in the acute post-injury phase (within 56 days of injury) (Dobkin et al[22 23]). Four further case series were excluded as their samples sizes were <10. FES systems, which involve walking training, either overground or treadmill e.g. Parastep I are reported in NMS section.

- **Neuromuscular Electrical Stimulation (NMS):** This included (a) Functional Electrical Stimulation (FES) and Patterned Electrical Stimulation (PES). The definitions of this are borrowed from the SCIRE report; both are types of neuromuscular electrical stimulation employing cyclical patterns of electrical stimulation that simulate natural muscular activity, however, FES "is directed at the attainment of purposeful movement such as walking or cycling[4]" whilst PES, on the other hand, is focussed on producing muscle contractions that may be used to generate muscle force such as an isometric condition[4]. In some applications, PES techniques have been used as a training stimulus to prepare muscles for a subsequent FES training condition[4]. One RCT and 10 case series were reviewed.
  For the purposes of this review transcutaneous electrical nerve stimulation is included as 'patterned electrical stimulation' intervention. One RCT met the project brief.

- **Electromyographic Biofeedback:** Two RCT's were reviewed.

Body-weight-supported treadmill training (BWSTT)

Health Technology

Patients walk on a motorised treadmill with varying degrees of body-weight support via an overhead secured body harness. As the patient regains strength and voluntary limb control, the body-weight support is reduced.

[⊕] BWSTT also referred in the literature as Laufband training

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An adjunct to BWSTT is the robotic gait-driven orthosis (The Lokomat®). This consists of a motorised-gait-orthosis akin to a motorised pair of lower limb callipers into which the patients' legs are placed. The callipers are computer controlled to move in a set gait pattern. The Lokomat® is used in conjunction with a standard treadmill. The patient may also have additional body-weight support via an overhead suspension system[24].

Both New Zealand spinal units have body-weight supported treadmill facilities. One company marketing its treadmill product (the NUberwalker) as 'low cost', is priced at NZ$20,500. It appears, however, the treadmill itself is additional cost. Robotic gait driven treadmill systems are substantially more complex and expensive; a current quote for a base model Lokomat® is NZ$452, 310.40.

Results

Three RCT's, one non-randomised comparative trial (two publications) and eight case series met the inclusion criteria and were appraised for this report. Although all trialled BWSTT, there was significant variation in terms of BWSTT interventions across the studies; interventions included; BWSTT with concurrent manual/therapist assistance; BWSTT using the Lokomat® (two RCT's and one case series); BWSTT delivered concurrently with conventional therapy (one non-randomised comparative trial) and BWSTT with concurrent FES to lower limb muscle groups (one RCT and three case series). Some of these studies are discussed in more detail below. All studies reviewed for this report are tabled in Appendix 3.

Field-Fote et al (2005[25]) randomised subjects to one of four study groups: 1. overground walking (BWS overground walking (OG) with peroneal muscle stimulation (n=7)); BWS treadmill walking with physical therapist assistance (n=7), BWS treadmill training with peroneal muscle stimulation (TS) (n=7) and robotic treadmill training (Lokomat®) (n=6). Randomisation into the treatment groups was "stratified based on Lower Extremity Motor Scores". All subjects' level of injury was above T10 and all subjects were more than one year following injury.
Treadmill training was substantial in terms of intensity frequency and duration (45 minute sessions, 5 days/week for 12 weeks). Improvement in walking speed from baseline to follow-up was measured in *all* groups, with a mean increase of 55% (all groups combined) for the 6-metre walk to 37% for the two-minute walk. Only the TS (0.11-1.75m/s) and OG training groups' 6-metre walk speed (0.14-0.19 m/s) improvements were statistically significant. Study power was insufficient to compare the changes between groups at follow-up.

Whilst at first glance, the authors have chosen an appropriate methodology to investigate the impact of *different types* of treadmill training on walking parameters, this does not allow the reader to determine the efficacy as compared with usual care. The baseline characteristics of the group were also not analysed and raw data indicated there may have been substantial

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differences between the groups in terms of age, injury level and initial Lower Extremity Motor scores.

Whilst these differences may be congruous with the stratification method described, such an approach does not appear sensible to enable treatment comparisons to be made.

Details regarding assessor blinding was lacking and furthermore, with such a small sample few conclusions can be made regarding the efficacy of one treadmill training type over another (SIGN grading 1-). Adverse events were not reported.

Postans et al (2004[26]) assessed BWSTT with concurrent FES in a cohort of incomplete spinal cord injuries. Outcome measures were: the 6-minute walk, walking speed, stride length and steps/minute. The group largely comprised sub-acutely injured spinal cord injured (SCI) subjects (n=14 total, 9 "acute"). Results were reported for five subjects only per group (7/10 > 10 weeks post-injury) due to two withdrawals and missing data for two further subjects. Subjects were randomised into control/intervention or intervention/control groups, the control being standard Physical Therapy 5 days/week; the intervention was 5 days/week of BWSTT and FES (25 mins/max/session). Four weeks of treatment was then followed by a 4 day assessment (washout) period; the subjects then received the alternate treatment.

Results were poorly reported with a substantial amount of baseline data absent. Raw data indicated walking distance increased substantially for the five subjects following BWSTT and FES in the control/intervention group. The reverse was seen in the intervention/control group; greater distance was walked at the end of the control period compared with the end of the intervention period. This may reflect an additive effect of both treatment periods and therefore indicate an insufficient washout period (SIGN grading 1-). Adverse events were not reported.

Hornby et al (2005[27]) randomised subjects into one of three treadmill training regimes (n=35 total, n=10 per group). The three trial arms were: (1) robotic-assisted BWSTT using the Lokomat®; (2) BWSTT assisted by a physical therapist and (3) overground ambulation with a mobile suspension system for safety. Five subjects in total were lost to follow-up. Complete and incomplete injuries (with some voluntary motor control in the lower limbs) only above T10 level were enrolled, with weekly treadmill training up to 90 minutes (usually 3 x 30 minute sessions) or walking up to 3km maximum per week.   Baseline demographics and functional abilities were statistically similar across the groups. Eight-week data indicated there were no statistically significant differences between groups for Lower Extremity Motor Scale (LEMS) scores, spasticity, sitting or standing balance, Functional Independence Measure (FIM) or Walking Index for Spinal Cord Injury (WISCI) scores; despite this, data indicated some improvement from baseline to follow-up with respect to FIM, WISCI and LEMS scores across all groups (change data graphed only). This paper was graded 1- due to insufficient detail regarding study design and poor reporting of the results. No explanation was provided for the five losses to follow-up and adverse events were not reported. Furthermore, the study

included an unknown number of 'post-acute patients' (post-injury range from 14-180 days).

A randomised controlled trial standardly uses a control intervention which is the 'gold-standard' current treatment. Both RCT's, however, used multiple treatment arms with no true control. The authors justified this methodology by stating previous publications had proven the efficacy of BWSTT. The literature search undertaken for this EBH report did not however identify literature to support this statement.

Two further low quality publications relating to one non-randomised comparative trial investigated walking and functional outcomes following BWSTT (Wernig et al, 1995 and 1998 [9] [10]). The original paper compares BWSTT results in a mixed sample of chronic and acute SCI patients (n=89) with those undergoing conventional therapy (n=64). The latter paper reports long-term (6 months to 6.5 years post-treatment) results from the mixed cohort (n=76; unknown mix); this group included some subjects that were included in the original study, some new subjects and some that were involved in the original study, but not reported.

Although the 1995 study promised much having a substantial sample, both papers fell short of being quality publications. Both failed to report appropriate baseline or outcome data, and largely described outcomes with limited data analysis. The authors of the 1995 paper reported significant improvement was made in walking ability following BWSTT ("locomotion ability improved in almost all of 44 chronic subjects"). Six of the 44 chronic subjects were able to staircase walk at the start of the study; this improved to 34/44 by the study end. Treatment duration varied significantly across both the acute (3-16 weeks) and chronic SCI groups (3-20 weeks). Importantly, however, the BWSTT group underwent concurrent "conventional therapy" which may have confounded the results. The authors' conclusions from the long-term follow-up[10] study (no additional BWSTT interventions administered) showed that improvements made from the original intervention were "…generally maintained. One patient deteriorated by one class and three improved one or two classes". These conclusions, however, cannot be relied upon with any certainty due to the poor methodology and reporting; the authors also used an unvalidated outcome measure of walking ability. Both papers were graded 2- using the SIGN criteria which reflect the poor reporting and design. Adverse events were not reported in either paper.

Eight publications reporting on seven case series enrolled subjects that were *largely* > 1 year post-injury. Two case series included an unknown number of patients in the acute and sub-acute[28] [29] (<80 days) phases post-injury. Sample sizes were small ranging from 9-32, and four case series[30-33] only (n=14-20) reported functional and/or walking outcomes in any detail. These four case series all demonstrated improvements in walking speeds and distance following treatment. They all, however, also involved substantially different programme durations (eight weeks -12 months).

Wirz et al (2005[33]) assessed walking outcomes following eight weeks of Lokomat® BWSTT training in 20 subjects. Significant improvements were reported in patients' 6-minute walking test scores and reductions in the 'Timed-up and go' walking test following treatment. WISCII-II scores, however, indicated two subjects only showed improvement over time (NSS♠, p=0.22). None of the subjects who were unable to walk prior to the training regained walking ability following treatment. These are promising results in terms of walking time and distance, however, disappointing with respect to changes in functional walking ability. Eight weeks of treatment seems a reasonable treatment period, although it would be interesting to see if functional changes resulted if the programme was longer.

Hicks et al (2005[34]) evaluated the effect of BWSTT following thrice weekly sessions over a longer period (12 months) in a group of 14 chronic SCI individuals. Follow-up assessments were undertaken at three-monthly intervals during the study and eight months after the study was completed. Four patients only improved their overground walking ability (by 1, 2, 2 and 4 points on the Modified Wernig scale∝) at 12 months. Walking speed, (0.5-1.4m/s; p<0.01) and distance (221.4-961.7m; p<0.01) did, however, significantly increase from baseline to 12 months. Again, improvements this time in walking speed and distance are seen, but transference to function did not result in the majority of subjects. Data from eight-month follow-up indicates that three of the four subjects that improved their overground walking scores from baseline to 12 months maintained these improvements at 20 months. No subjects with high levels of injury made significant progress either at 12 or 20 months. One high injury-level subject only improved slightly at the 12-month follow-up (2 points on the modified Wernig scale).

Six further case series[32, 28-30, 35, 36] were reviewed, three of which included concurrent FES[30, 35, 36] (quadriceps or common peroneal nerve). Two case series[28, 29] were very poorly reported. These are reported in the study tables only.

Two case series by the same authors reported results following concurrent BWSTT and FES[30, 35] (19 and 14 subjects respectively). Both case series involved a regime of thrice weekly treatment over three months. Field-Fote (2001[30]) reported mean overground walking speed increased from 0.12-0.21m/s (p=0.0008) from baseline to study end; treadmill walking speed increased from 0.23-0.49 m/s (p=0.00003) and LEM scores increased by a

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♠ NSS=non-statistically significant.

∝ Modified Wernig Scale used for measuring functional walking in addition to distance, speed and body-weight support. Modified Wernig Scale;0=No walking capability, even with help of two therapists; 1=Capable of walking<5 steps with the help of two therapists or along parallel bars; 2=Capable of walking≥5 steps with the help of two therapists or along parallel bars; 3=Capable of walking >1 length of the parallel bars, requiring assistance to turn; 4=Capable of walking >1 length of the parallel bars, turning independently; 5=Capable of walking along railing (<5 steps) with the help of one therapist; 6=Capable of walking along railing (>5 steps) with the help of one therapist; 7=Capable of walking with a rolling walking frame >5 steps; 8=Capable of walking with canes or crutches >5 steps; 9=Capable of walking without devices >5 steps.

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *24*
I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

median of 3 points from baseline to follow-up (p<0.005). Long-term follow-up of four subjects (2 months-1 year) indicated overground walking speeds "as good" or "better" than that of their final post-study evaluations. No data, however, supports this conclusion.

Thomas and Gorassini (2005[32]) investigated the impact of BWSTT and manual therapy assistance in a group of 10 chronic incomplete spinal cord injured subjects. Body weight support (BWS) requirements reduced from a mean of 44.3% at baseline to 13.4% at study completion. All but one subject improved walking function with WISCI-II scores improving from a mean of 6.4-9.8 (p=0.027) following an average of over 16 weeks of treatment. Six-minute walking distance also increased from a mean of 34.2-167.7m (p<0.01). Two subjects assessed 2.5 years following training maintained the walking gains. Adverse events were not reported.

Safety

A single case series (Ferro et al 2007[36]) specifically investigated the impact of BWSTT and NMS on patients' knee joints (using MRI) and reported the correlation between clinical and radiological findings. All 9 subjects had sustained cervical lesions. Following six months of relatively low-level BWSTT (20-minute sessions, 2 sessions/week), four subjects were identified with radiological evidence of minor-moderate knee pathology. Three of the four were deemed clinically important. The authors acknowledged that determining whether the pathologies identified were as a result of atrophy over time or attributable to the BWSTT was difficult. Pre BWSTT imaging was not performed.

One RCT[26] and one case series[31] reported withdrawals from BWSTT training. The reasons were not specified.

Table 2 summarises the case series for BWSTT.

Summary

Improvements in walking distance and/or walking speed are reported consistently across all studies. Only some of the studies, however, used valid walking measures or reported functional outcomes. Low quality evidence from two RCT's that studied varied BWSTT interventions indicate walking speed improvements. A further RCT comparing BWSTT with standard interventions also reported walking speeds improved following BWSTT.

Information on how patients responded to BWSTT at a functional limitation level (WISCI or modified Wernig) is available only from one RCT and three case series. The RCT although reported significant WISCII score improvements was of poor quality and compared various BWSTT interventions. Three further case series only (n=44 total) report conflicting findings. Two case series reported clinically improvements in WISCI-II scores after 16 weeks of treatment (one with 2/10 subjects only improving WISCI-II scores). One further case series indicated function did not improve (as measured by the Instrumental Activities of Daily Living Scale) despite improvement in walking parameters. The literature therefore is small in volume and conflicting and conclusions cannot be made.

Three case series inform the discussion regarding the maintenance of impairment and functional gains long-term following BWSTT. Data from three case series indicating that overground walking speed and/or ability is maintained 2-12 months following BWSTT is from 10 subjects only. One of these studies reported at 8 months after study completion that patients had reduced satisfaction with their physical ability despite being assessed as equally capable compared to study completion.

Based on the paucity of data, therefore, it is unclear whether impairment and functional gains following BWSTT are enduring.

There is weak evidence to support the effectiveness of a variety of BWSTT interventions with respect to improving impairment (e.g. walking distance/speed) with chronic spinal cord injured subjects. The evidence is unclear as to whether functional gains result. The evidence is also unclear as to whether improvements of any kind are enduring.

Although three RCT's were amongst the literature, these were poor quality. Case series data provides more convincing evidence although these involve small samples and themselves have methodological issues.

There is insufficient evidence to date regarding the effectiveness of BWSTT with respect to determining the effectiveness of BWSTT interventions for specific:

Specific levels of injury
Pre-treatment Level of baseline physical ability
Time since injury

This is due to the small volume of literature, intervention heterogeneity and inadequate data analysis. One small case series provides data to suggest

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *26*
I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

cervical injuries appear to not make the impairment and functional gains from BWSTT as seen with lower level injuries.

Most studies administered BWSTT interventions 3-5 x per week for 2-3 months. Producing high quality studies and analysing the data to determine who most benefits from an intensive, expensive intervention will be important

The availability of equipment and providers may also be an issue.

Safety

The evidence for safety for all types of BWSTT is unclear. One case series only considered whether BWSTT is a safe intervention. This was a small case series specifically assessing the integrity of knees using MRI following BWSTT and NMS. A number of cases of joint abnormality were identified. Cause and effect is not, however, clear. The possible impact on particularly the musculoskeletal system of such an intervention may be important. It would be important to clarify the safety of this intervention if purchasing was to be considered.

Table 2: BWSTT – summary table - case series

AUTHOR	YEAR	SAMPLE SIZE	TIME POST INJURY	TREADMILL DETAILS			COMMENTS
				Intensity	*Frequency*	*Duration*	
Ferro et al	2007	9	All > 1yr post-injury	30-50% BWS	2 x 20 minute sessions/week	6 months	BWSTT and NMS to quadriceps Stimulation of quadriceps for 5 months prior to treadmill training **Safety study**
Wirz et al	2005	20	2-17 years post-injury	BWS as low as possible	45 min session/ 3-5 x week	8 weeks	Lokomat® – driven gait orthosis
Hicks et al	2005	14	1.2-24 years post-injury	BWS commenced at ≥60%, customised as patient progressed	3 bouts, 10-15 minutes/session	144 sessions max	
Field-Fote & Tepavac	2002	14	12-171 months	Customised BWS	1.5 hrs/session, 3 days/week	3 months	Combined with FES to the common peroneal nerve Limited functional reporting
Thomas & Gorassini	2005	10	≥ 1 year post-injury	Manual assistance as required	1 hr/session, 5 sessions/week	3-5 months Training stopped when improvement plateauxed	BWSTT + manual assistance Limited functional reporting
Field-Fote	2001	19	12-171 months post-injury	No parameters stated	1.5 hrs/day, 3 days/week	3 months, to a total of 36 sessions	BWSTT + FES to common peroneal nerve
Wirz et al	2001	32	32-347 days post-injury	BWS customised	Up to 300m, 1.5 km/hr, 5 days/week	"training lasted 137 days"	Includes some acutely injured patients
Colombo et al	1998	12	49-323 days post-injury	BWS up to 80% Therapist-assisted leg movements as required	Up to 300m, 1.5km/hr, daily	Not stated	Includes some acutely injured patients

× = BWS: body-weight support

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *28*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Neuromuscular Electrical Stimulation (NMS)

Health Technology

Three distinct types of neuromuscular stimulation were identified from publications relating to this report:

(1) Functional Electrical Stimulation (FES): is the application of an electrical stimulus to specific muscle groups via implanted or surface electrodes to generate a muscle contraction that is "directed at the attainment of purposeful movement such as walking or cycling"[4]. Commercially available neurostimulator systems' trials were reviewed for this report if they reported on functional measures (e.g. Parastep I - a four or six channel microprocessor controlled stimulator with modified walking frame[37], approved by the US Food and Drug Administration in 1994). The purpose of the neurostimulator systems such as the Parastep is for the individual to engage in exercise for secondary benefits rather than use the system to improve their walking ability[38]. These systems have also been described in the literature as "an alternative not a substitute for a wheelchair"[39].

Applying FES via superficial electrodes, appears to be used for training and exercise and in some cases is a preliminary step to determining the utility and need for electrode implantation. This would theoretically mean that walking improvements could also be used to accomplish functional tasks.

(2) Patterned Electrical Stimulation (PES): PES may also be defined as the application of an electrical stimulus to specific muscle groups via implanted or surface electrodes to generate a muscle contraction. In contradistinction to FES, however, PES aims to produce muscle contractions that may be used to generate muscle force "such as an isometric condition", and PES is used often to train "muscles for a subsequent FES training condition"[4].

Neuromuscular stimulators for PES or non ambulatory FES conditions range from as little as NZ$90.00. The systems, however, that are likely most suitable for spinal cord injured patients are the more robust, expensive versions with a number of stimulation channels. These currently cost over NZ$4,000. The cost of a four- channel Parastep Ambulation FES system is currently NZ $15,588.00 and the six-channel, NZ$16,897.00.

(3) Transcutaneous Electrical Nerve Stimulation (TENS): is defined as the application of a series of electrical stimuli applied to the skin via surface electrodes to preferentially stimulate large diameter sensory fibres (e.g. Alpha fibres). The stimuli differ with that delivered by FES and PES in terms of intensity, wave form and duration. By and large TENS is used clinically for pain management purposes via peripheral and central

ACC Evidence based healthcare team   *29*
Intensive Exercise Programmes for Spinal Cord-Injured
individuals   *- -*

neural mechanisms. It is thought predominantly to be effective through the blocking of slow fibre pain impulse transmission at the spinal cord level (Gate Control Theory).

TENS machines are the cheapest neural stimulation equipment but it is fair to say, likely the least useful for improving function following spinal cord injury as TENS is generally used for pain management in an intact nervous system and is not designed with the purpose of stimulating muscle for strength or function. TENS are readily available from a number of suppliers from upwards of NZ$100.

Results

Three RCT's were identified regarding neuromuscular stimulation (1 X PES, 1 X FES, 1 X TENS). Two studies used quasi-randomisation methods, with a restricted randomisation process to ensure intervention groups were of a similar degree and level of injury[7 40]. Importantly, some BWSTT studies already discussed involve the concurrent use of FES. These studies are not considered in this section.

The single RCT investigating FES (Kohlmeyer et al[41]) (n=21) was excluded as it related to the acute post-operative period. Two further papers were also excluded on the basis they reported no functional outcomes but otherwise met the inclusion criteria (Wen[42], Heesterbeek et al[43]).

Klose et al (1990[7]) used a quasi randomised cross-over design to specifically assess the impact of a *PES* regime at 8 and 16 weeks in a group of 39 incomplete cervical-cord injured subjects. The intervention groups (10 per group) were as follows:
1. EMG biofeedback (8 weeks) then physical exercise therapy (8 weeks)
2. EMG biofeedback (8 weeks) followed by PES (8 weeks)
3. PES (8 weeks) followed by physical exercise therapy (8 weeks)
4. Physical exercise therapy (16 weeks continuous).

EMG and NMS were applied to the biceps, triceps, wrist extensors and wrist flexors bilaterally. Exercise therapy included upper limb strengthening, mat mobility, wheelchair skills, self-care training and transfer skills. All interventions were administered thrice weekly for an unknown intensity and duration. These interventions generally targeted subjects' upper bodies. Results both at 8 and 16 weeks indicated gains in mean manual muscle test scores, self-care scores, a mobility score and EMG recordings in all groups. No between-group differences were found either at 8 or 16 weeks. Although the study findings then suggest PES is no better than other conventional methods of treatment, interventions applied well after injury do appear to have had a positive impact.   This study, however, was poor quality and involved a small sample. Issues concerned lack of methodology detail and absent data reporting (SIGN grading 1-).

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *30*
I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

Aydin et al (2005[40]) assessed the impact of either oral Baclofen or TENS on spinal cord-injured patients receiving concurrent exercise therapy. Outcomes measured were spasticity parameters and functional independence. Interestingly, the purpose of the TENS application in this case was used with the aim of improving spasticity with potential carry over to improving physical function rather than improving pain.

There were an unknown number of post-acute patients in this study (mean time post-injury 11.5 months both groups, range 2-49 months). Five of the 11 subjects in the TENS group were female; all subjects in the Baclofen group were female. Subjects were randomised to eight weeks of medication (5mg increase every 3-5 days until "adequate clinical response" was achieved – maximum of 80mg/day) or TENS (bilateral tibial nerve stimulation, 15 minute sessions, once daily, maximum 15 sessions) with both groups receiving concurrent exercise therapy. Statistical and likely clinically significant improvements were seen in both groups across most variables from baseline to trial end, including FIM scores. FIM scores in the Baclofen group improved from a mean baseline of 67 to 75.7 at study completion; mean FIM scores in the TENS group also improved significantly from 68.5 to 76.2 over the same period. No statistically significant difference was seen between the two groups at last follow-up. This study is interesting in that results indicated that TENS and Baclofen both appear to have a similar positive impact on spasticity, and that this carries over into improved function. There is the question, however, whether, these improvements were at least, in part, the result of the concurrent physical therapy both groups received. To identify a non-pharmacological option to assist in the management of spasticity would appear to be important, as spasticity can cause pain, result in joint contractures and contribute to the development of pressure sores.
This study also, however, was poor quality and involved a small sample; methodological concerns included poor detail regarding randomisation, limited blinding and no concealment allocation (SIGN score 1-).

A further ten case series studied the effect of FES with chronic spinal cord-injured subjects. Three case series[38 39 44] assessed the effect of the Parastep I FES ambulation system, two involved FES cycling[45 46] (one of which specifically assessed the safety of the intervention) and the remainder reported outcomes for FES (various numbers of channels) for standing and/or walking. There was significant variability across all studies regarding degree of injury (complete vs incomplete) and level of injury. This would be expected for FES cycle trials, however, substantial variability was seen also amongst those case series using FES for standing and/or walking, including Parastep ambulation studies. Case series programme duration varied from 3 months to 4 years. Limited data was available for subjects at the longer end of the intervention spectrum. FES trials for standing and/or walking (including Parastep trials) involved overall, small samples (10-20 subjects).

The study undertaken by Kralj et al (1988[47]) had the largest sample of all the studies with 76 subjects (50 complete, 26 incomplete, range C6-L1). Subjects received one 30-minute FES session daily for between eight and 16

weeks to assist standing and/or walking. Following treatment, all T4-12 patients were able to stand using FES although half of the patients between T4-11 level of injury did not achieve four-channel walking. Of the 25 patients that did, only seven were able to master crutch walking. Walking speed of these subjects in particular was reported as between 12-18 metres/minute, with a total distance achieved of 100-200 metres.   Patients had the option of continuing FES at home following the completion of the study. Sixteen of the 25 that were independent with four-channel FES at home remained ambulatory after three months of home use, with drop-off due to the time required to fit the system. Twelve of the 17 patients able to stand with FES following treatment were still using the system at three months. Those patients that used a two-channel quadriceps stimulation unit reported that they now had a free hand to perform a manual task. These numbers seem to suggest that ongoing FES use in the community may be limited. This study does not provide particularly helpful data when considering the efficacy of FES as it is largely descriptive. Data indicating the use of walking aids following treatment is absent and the results from "incomplete" subjects were summarised only.

Ladouceur and Barbeau (2000[48]) reported results from a small trial (n=14) where subjects were trained to use FES for walking and then encouraged to use FES to ambulate in the community. After one year, maximal overground walking speed over 10m both with the FES orthosis had improved by 0.26 m/s (p=0.001; increase from 0.51-0.78m/s) and without the orthosis by 0.25 m/s (p=0.000; increase from 0.49-0.74m/s). Two subjects only failed to show any improvement in maximal overground walking speed. Longitudinal analysis of the data indicated that there was no correlation between these improvements and the subjects' functional categories (e.g. community walker vs home walkers). The gains seen were also were similar irrespective of baseline walking aids used by the subjects. The authors also reported that subjects "reduced their dependence on walking aids". No data, however, was provided to confirm this conclusion. Improvements over time by and large followed a progressive linear pattern. It is also noted that those that were fastest walkers at baseline made the greatest absolute change. Although the results are largely reported at one year, some results appear to be up to four years following first use. This is a small study, although does provide some data that suggests the gains from FES assisted are substantial and result in walking improvements without the the orthosis. This view conflicts with that of other researchers' that FES walking is just an "exercise modality"[38 44] and has no role in functional walking. Adverse events were not reported.

Wieler et al (1999[49]) also demonstrated similar gains with non-orthosis walking. A statistically significant improvement in walking speed from baseline to follow-up after FES walking training without the device (n=47, mixed cohort of spinal cord and stroke injuries) was reported (up to 180 weeks of treatment). The 'training effect' (i.e. walking improvements seen when assessed without the orthosis) accounted for over 50% of the improvements recorded in subjects' walking speed. The study did not use the Parastep, but

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *32*
I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   *- -*

a 1-4 channel stimulation system; the size of the training effect seen varied depending on patients' initial speeds; those able to walk >1m/s at baseline showed the largest improvement in terms of total change and training effect (i.e. with and without the FES system). Responses from an unvalidated questionnaire showed 73% agreed that the device helped them do the things that were important to them and 97% agreed they would like to continue FES for walking (30 responses/47).

Results from this study then seem to suggest that good continued patient use of the system in the community may occur (23/31 subjects) (unknown assessment time following study completion). Such findings conflict with those of Kralj et al (1988[47]) that indicated relatively poor long-term compliance with FES use. Reasons for not continuing were, however, the same: lack of time (n=4) and lack of progress (n=4).

As the time and effort to don and doff the orthosis appears to be substantial, the ability and desire of patients to use the FES systems for standing and/or walking on a long-term basis is an important consideration. It is also apparent that there is a significant metabolic expense incurred with walking using these systems. This may also be a factor that could impact on compliance with its long-term use.

Results from a small case series that studied oxygen uptake and walking speed over a single bout of of FES walking[50] (several minutes) indicated increases in walking speed of 4m/minute with reduced oxygen requirement. Most subjects had superficial FES, but two had implanted electrodes. Injury level ranged from C2-T10, all with incomplete injuries.

The remaining case series[38 39 44 51] reporting on FES concur that improvements in walking distance and/or speed (impairment gains) do in fact occur. The single study[51] using FES for standing was undertaken with the purpose of indicating FES was a viable intervention.

Three case series[46-48] reported real-world walking ability improvements and/or improved ability to undertake functional tasks as a result of these impairment gains. The results, however, were all descriptive in nature (e.g. "all incomplete patients reported subjectively improved function and wellbeing after 3 months"[46]) and the data to corroborate these conclusions is absent or unconvincing.

One final paper[46] reporting outcomes from 12 subjects that underwent FES cycling for up to two years indicated statistically significant strength gains in quadriceps and hamstrings musculature and subjective reports of improved function. No raw data, however, corroborated this latter conclusion and all patients underwent concurrent standard physical therapy, which may have confounded outcomes. Spasticity changes were variable. Two withdrawals occurred due to increased muscle spasm (SIGN grade 3).

Table 3 provides a summary of the case series reviewed for this report.

Safety

Regarding NMS interventions, One RCT[7] and two case series only *failed* to report adverse events and/or discuss safety issues[48 50].

Parastep system

Gallien et al (1995[38]) reported six adverse events (n=13) using the Parastep I system; these included back pain and ankle sprains and one case each of a calcaneal and a sacral fracture. Brissot et al (2000[44]) reported a significant number of adverse events also from a small cohort of 15 subjects. These ranged from the more serious (pressure sore, n=1, falls, n=4 of which one patient sustained a sacral fracture) to pain from electrostimulation resulting in study withdrawal (n=1), back pain (n=4) and transient ankle oedema (n=4). Klose et al (1997[39]) reported no adverse events from their 11 week programme (n=16).

All Parastep studies were clinic-based with appropriate supervision and used the 6-channel stimulator. Furthermore, all studies had clear guidelines regarding the minimal quadriceps strength that needed to be achieved prior to commencing walking. The studies also appear to use similar walking session length and frequency.

Other NMS studies

Nash et al (1994[45]) scanned the femoral heads and dominant knees using MRI in subjects that had undergone more than 1.5 years of rehabilitation with FES cycling (range 1.5-5.7 years). Seven of the 10 subjects showed MRI evidence of pathology. These included one case of microfracture of the medial femoral condyle, one case of avascular necrosis of the distal femur, lateral femoral condyle and tibial plateau and three cases of knee meniscal defects. As pre-treatment MRI scans were not performed and subjects only clinically screened for pathology, bone and joint integrity changes reported cannot be attributed to the FES treatment with any degree of confidence. These changes may have been pre-existing, or occurred as a result of other treatments administered.

Balmaseda et al (1987[52]) reported of two occurrences of burns as a result of NMS. The author reported these both resulted from NMS being administered over areas where there was reduced skin sensation.

Other minor adverse events reported in small numbers across the studies were transient skin irritation[49] (upper limb NMS) and two cases of increased muscle spasm that resulted in patients withdrawing from the study[46] (FES cycling).
The kind of adverse events reported above, come as no surprise, considering the nature of the intervention, however, may be significant.

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *34*
I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

Summary

FES

Effectiveness
There is weak evidence to support that FES is beneficial for walking parameters (speed and/or distance) sub-acute and chronic spinal cord-injured subjects. Evidence comes from eight relatively low quality, low sample size, case series.

Evidence to suggest that walking speed and distance gains may also result in functional improvement comes from three case series only. Claims of functional improvement, however, cannot be adequately substantiated due to absent or unconvincing data.

Safety
The evidence to support the safety of FES across the different interventions is unclear. There is evidence from two case series that serious adverse events have resulted from FES interventions. Both case series involved Parastep FES systems. The majority of case series, however, reported few and minor adverse events.

PES
Safety and effectiveness
There is insufficient evidence to support the safety and effectiveness of PES for the purpose of improving function with sub-acute and chronic spinal cord-injured subjects. Evidence is from one small poor quality quasi- RCT that compared PES with standard physical therapy and biofeedback to the upper body over 16 weeks.

TENS
Safety and effectiveness
There is insufficient evidence that TENS may be effective and safe for the chronic spinal cord injured population for the purposes of improving standing and walking. Evidence comes from one low quality RCT comparing TENS with oral Baclofen to improve function via its impact on spasticity. Both treatments indicated effectiveness for reducing spasticity and enhancing function. The likely side effects from TENS are more likely to be burns as TENS is not used for muscle contraction/walking purposes.

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Table 3: Neuromuscular electrical stimulation – summary table –case series

AUTHOR	YEAR	STUDY TYPE	SAMPLE SIZE	TIIME POST INJURY	ELECTRICAL STIMULATION DETAILS			COMMENTS
					Intensity	Frequency	Duration	
Wieler et al	1999	Case series – multi-centre trial	40	31 SCI; 29 chronic SCI subjects, 2 within 1 year of injury	1-4 channels	Customised; community walking	Up to 180 weeks – no raw data to assess range	**FES walking** Some statistical comparison of effect of FES walking on stride, step length and walking speed between SCI and cerebrally injured subjects
Ladouceur & Barbeau	2000	Case series	14	1.8-19 years post-injury	Quadriceps and peroneal nerve stimulation	Fes use in the community following four weeks of adjustment time to the FES		**FES-assisted walking** Poor reporting; One-year results primarily, although an unknown number reported up to four years; unable to assess raw data; unknown adherence to stimulator use No adverse events reported
Brissot et al	2000	Case series	15	6-240 months post-injury	6-channel stimulator One session daily		Total sessions 30 Follow-up reported as 40 months average	**Parastep I ambulation system**
Klose et al	1997	Case series	16	Mean post-injury time of 4 years	Up to 3 walks per session; Hz=24 PW=150μs Output=09-300mA Allowed 15-20 minute rests during sessions; Unknown session length	3 x weekly	Total of 32 sessions over 11 weeks	**Parastep I ambulation system** - stimulator and modified walking frame No disability or overall functional measures No adverse events reported

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AUTHOR	YEAR	STUDY TYPE	SAMPLE SIZE	TIME SINCE INJURY	STIMULATION DETAILS			COMMENTS
					Intensity	*Frequency*	*Duration*	
Gallien et al	1995	Case series	13	5-240 months since injury	2 hours/session	3-5 x/week	32 sessions	**Parastep I ambulation system**
Sloan et al	1994	Case series	12	2 months-11.5 years since injury	30 minutes	3x/week	Three months	**FES cycling** Assessed ADL's, bone mineral density, isokinetic strength
Nash et al	1994	Case series	10	.5-13 years post-injury	1 month quadriceps muscle training prior to starting FES cycling 30 minutes/session	2-3x/week	1.5-5.7 years of treatment (mean 2.6 years)	**FES cycling** **Safety study** MRI imaging to assess knee integrity
Stein et al	1993	Case series	10	2.5-10 years post-injury				**FES for walking** All could stand unassisted prior to study
Yarkony et al	1990	Case series	25	1-13 years post-injury	2 x 60-90 minute sessions daily	Home standing with standing frame once managed sessions independently	6 months	**FES for standing**
Kralj et al	1988	Case series	76	Time post injury – not stated; "Most (66%) started within 24 months of injury"	30-60 minutes/session	One session daily	8-16 weeks	**FES for standing/walking** Progressed walking aids as patients able Limited functional reporting

Electromyographic Biofeedback

Health Technology

Electromyographic biofeedback is a monitoring device used for a variety of neurological and musculoskeletal diseases and conditions. In rehabilitation settings it is commonly used to facilitate muscle contractions from individual muscles or groups of muscles where there is motor inhibition. Information regarding electrical activity in the body is relayed via surface electrodes and projected visually and/or auditorally back to the subject (speaker/monitor). Using this information the subject can be trained to respond to abnormal measurements in involuntary function with specific therapeutic actions, such as muscle relaxation, meditation, or changing breathing patterns. Biofeedback is via surface electrodes fixed to the relevant muscle groups[53].

Results

One RCT reported the impact of EMG biofeedback as an adjunct to physical therapy training (Klose et al, 1993[8]). One further quasi-randomised study by the same authors included EMG biofeedback as two of four trial arms, largely looking at the effectiveness of biofeedback administered concurrently with other interventions[7]. This has been considered in terms of effectiveness of PES.

The purpose of trialling the EMG biofeedback in the Klose et al (1993) paper in this cohort was to create/encourage contraction of the muscles over which the surface electrodes were placed. Thirty-one subjects were randomised in to two groups based on their levels of injury. Baseline testing indicated these groups were balanced. Both groups received 45 minutes of exercise therapy, 3 x per week of and 30 minutes of neuromuscular stimulation 3 x per week to their upper body musculature for 12 weeks. The intervention group subsequently also received 3x 30 minute sessions of EMG biofeedback to their upper body musculature for 12 weeks.

Muscle strength measurements using a modified ASIA muscle grading scale (Appendix 4) and an unspecified functional abilities scale (canvassing hygiene, feeding and dressing) indicated no differences between the groups at any time points, although both groups showed statistically significant improvements in both strength and function from baseline. This paper was of low quality with shortcomings with respect to blinding, concealment allocation. The strength measure used was not validated and the functional ability measure unspecified. Adverse events were not reported.

Summary

There is insufficient evidence to support the safety and efficacy of EMG biofeedback for the purposes of improving standing/walking and or other aspects of function for individuals with chronic spinal cord injury. Evidence comes from one RCT that was used as an adjunct to Physical Therapy. Adverse events were not reported although considering the nature of the intervention are unlikely to be a significant issue.

5. Discussion

5.1 Methodological quality

Integrated Rehabilitation Programmes

The sole case reports identified reporting on Coordinated Dynamic Therapy and Activity Based Restoration therapy were excluded from formal review. The single randomised controlled trial relating to Massed Practice Therapy was of poor quality and did not compare Massed Practice Therapy with traditional rehabilitation interventions; the findings are therefore of limited use.

Individual Modalities

There were no high quality papers that reported on the specific modalities of NMS, EMG biofeedback and BWSTT; trial samples were generally small and were heterogeneous in terms of length of time post-injury and injury levels. Variation in injury level is likely to confound outcomes. Specifically regarding BWSTT, there is debate as to the appropriateness of this intervention with complete spinal cord injuries. Whilst some researchers have reported that it is only beneficial with individuals with incomplete spinal lesions with some degree of voluntary lower limb activation[10 25 54] three of the trials that were initially considered for inclusion for this report enrolled subjects with complete lesions[28 29], and furthermore, generally failed to report results separately.

The RCT's reporting on both BWSTT and NMS also lacked detail regarding randomisation and failed to describe the blinding of assessors. The small samples reflects to some degree the fact that this population is generally small and scattered geographically. Blinding of patients with these interventions is unlikely to be possible. Few trials overall reported functional outcomes in any depth and with the exception of one paper, used functional outcomes that were either not validated or were unspecified.

Most studies reviewed for this report were case series with generally small samples also.

A very small amount of literature was identified that reported specifically on the safety of FES. One case series and one case report provide and BWSTT

(one case series). Case series present low level evidence but along with case reports is considered important when considering the safety of an intervention. This data presents important but inconclusive information relating to safety aspects of the intervention. One case series reported safety aspects of BWSTT and concurrent NMS. One RCT and three case series only reported adverse events relating to FES.

As the spinal cord population is relatively small, multi-centre trials would be the only sensible way to provide good evidence of safety and efficacy with such interventions. Trials also need to focus on functional and/or outcomes rather than changes in impairment (e.g. stride and step length, muscle strength and select appropriate functional and/or disability measures). The questions around safety can also be answered adequately by reporting adverse events from these clinical trials.

Other factors which may be important to ACC when considering the evidence for such interventions would be access to services and compliance with generally expensive equipment of equipment; compliance would be affected by many factors, but time to don and doff equipment, and the metabolic cost of its use are two factors that are reported in the literature and may be important.

5.2 Limitations of the review

This report has identified and reviewed literature specific to the sub-acute/chronic phase following spinal cord injury (>80 days post-injury at any spinal level). This eliminated a number of papers that investigated BWSTT and NMS for patients in the acute phase following injury. It is, therefore, important to recognise the conclusions in this report apply only to the chronic post-injury phase with this population. This could be considered a relatively narrow project scope.

Some literature initially meeting the first-cut of the review process was discarded after abstract and full paper analysis as it failed to report functional outcomes. The extrapolation of purely physiological and impairment measures to function is erroneous. Focussing on functional focus is appropriate, but emphasised the fact that the body of literature currently meeting this requirement is, indeed, very limited.

With serious injury clients such as spinal cord injuries, ACC is also interested in mitigating secondary complications post injury. It may be worthy to consider reviewing the literature for interventions administered for the purpose of mitigating secondary complications following spinal cord injury. Reviewing papers with the focus of functional restoration as has been done for this current report would be appropriate (e.g. bladder and sexual function), but other outcomes such as lipid profiles, and costs for attendant care for example due to immobility from pressure sores may need to be considered more broadly.

6. <u>Conclusions</u>

The evidence is unclear regarding the safety and efficacy of a small group of largely integrated intensive exercise programmes currently internationally available. This is based on one RCT and three case reports for three programmes. There is no data available for the single New Zealand provider of a semi-residential programme (Reactivate) for spinal cord injured clients. This programme does not appear to subscribe to any one specific rehabilitation philosophy.

There is a small amount of low quality evidence for the specific therapeutic modalities of NMS and BWSTT and for the post-acute and chronic phases following spinal cord injury. The outcomes, although in most cases indicate improvements in some impairment parameters of relevance to function, provide little certainty as to the efficacy of these interventions.

There is weak positive evidence for both BWSTT and FES for standing and/or walking coming largely from case series. Specific intervention parameters cannot be advocated due to the quality and heterogeneity of the literature. How enduring some of these reported improvements in walking parameters and function that result from BWSTT interventions is unknown.
Safety and adverse events have to date been poorly reported for both modalities and therefore the literature is unclear as to their safety. A number of serious adverse events have been identified in two case series using FES ambulation systems.
The risk of harm, must, therefore, be carefully considered before administering such treatments.

Implications for Purchasing and Policy Decisions: Purchasing intensive exercise programmes during the sub-acute and chronic phase following spinal cord injury with the aim of improving function and/or reducing disability is neither supported nor refuted by the current literature. Any decision to purchase such interventions either individually or in combination require a careful analysis of cost, benefit and safety risks.

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I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   *- -*

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I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

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I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d
i n d i v i d u a l s   - -

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Appendix 1: Search Strategy

Medline
1   exp Spinal Cord Injuries/ (26090)
2   (spinal cord and injur$).tw. (18452)
3   (parapleg$ or tetrapleg$ or quadrapleg$).mp. (14810)
4   paraplegia/ or quadraplegia/ (9461)
5   1 or 2 or 3 or 4 (42014)
6   exercise/ (39395)
7   exercise therapy/ (16150)
8   treadmill.mp. (15464)
9   Electric Stimulation Therapy/ (12259)
10   functional electrical stimulation.tw. (759)
11   lokomotor.mp. (1)
12   lokomat.mp. (5)
13   patterned electrical stimulation.mp. (27)
14   wheel.tw. (3619)
15   (intensive adj rehabilitation).mp. (268)
16   activity based restoration.mp. (1)
17   coordination dynamics.mp. (86)
18   co-ordination dynamics.mp. (1)
19   project walk.mp. (2)
20   beyond therapy.mp. (10)
21   passive motion.mp. (689)
22   central pattern generat$.mp. (838)
23   ((intensive or therapeutic) adj exercise).tw. (565)
24   (exercise adj routine).tw. (70)
25   or/6-24 (85394)
26   5 and 25 (1881)
27   limit 26 to human (1672)
28   (letter or news).pt. (714356)

29   27 not 28 (1642)

Embase

1   exp Spinal Cord Injury/ (19212)
2   (spinal cord adj injur$).tw. (11078)
3   paraplegia/ or quadriplegia/ (9251)
4   (parapleg$ or quadripleg$ or tetrapleg$).tw. (7850)
5   1 or 2 or 3 or 4 (28801)
6   exp kinesiotherapy/ (13541)
7   EXERCISE/ (56752)
8   ((intensive or therapeutic) adj exercise).tw. (424)
9   (exercise therapy or exercise routine).tw. (669)
10   TREADMILL/ (2610)
11   treadmill exercise/ (5769)
12   Electrostimulation Therapy/ (2757)
13   Functional Electrical Stimulation/ (101)
14   (lokomotor or lokomat).tw. (12)
15   patterned electrical stimulation.tw. (21)
16   wheel.tw. (2426)
17   (intensive adj rehabilitation).tw. (251)
18   activity based restoration.tw. (0)
19   (coordination dynamics or co-ordination dynamics).tw. (79)
20   beyond therapy.tw. (9)
21   project walk.af. (1)
22   Passive Movement/ (973)
23   central pattern generat$.tw. (648)
24   or/6-23 (80535)
25   5 and 24 (1238)
26   letter.pt. (354273)
27   25 not 26 (1209)
28   limit 27 to human (1085)

Cinahl

1   exp Spinal Cord Injuries/ (6134)
2   (spinal cord and injur$).tw. (4768)
3   paraplegia/ or quadriplegia/ (1815)
4   (parapleg$ or quadripleg$ or tetrapleg$).tw. (1708)
5   1 or 2 or 3 or 4 (8090)
6   exercise/ (9965)
7   therapeutic exercise/ (6111)
8   treadmill.mp. (1724)
9   electrical stimulation, functional/ (239)
10   functional electrical stimulation.tw. (262)
11   lokomotor.mp. (0)
12   lokomat.mp. (5)
13   patterned electrical stimulation.mp. (1)
14   wheel.tw. (353)
15   (intensive adj rehabilitation).mp. (142)
16   activity based restoration.mp. (0)
17   coordination dynamics.mp. (3)
18   co-ordination dynamics.mp. (0)
19   project walk.mp. (0)
20   beyond therapy.mp. (5)
21   passive motion.mp. (235)
22   central pattern generat$.mp. (16)
23   ((intensive or therapeutic) adj exercise).tw. (230)
24   (exercise adj routine).tw. (42)
25   or/6-24 (18557)
26   5 and 25 (558)
27   limit 26 to human [Limit not valid in: CINAHL; records were retained] (558)
28   letter.pt. (44437)
29   27 not 28 (556)
30   limit 29 to abstracts (437)
31   limit 29 to review (77)
32   30 or 31 (449)

AMED

1   exp Spinal Cord Injuries/ (3144)
2   (spinal cord and injur$).tw. (3457)
3   paraplegia/ or quadriplegia/ (862)
4   (parapleg$ or quadripleg$ or tetrapleg$).tw. (1521)
5   1 or 2 or 3 or 4 (4362)
6   exercise/ (6442)
7   therapeutic exercise/ (0)
8   treadmill.mp. (1146)
9   electrical stimulation, functional/ (0)
10   functional electrical stimulation.tw. (304)
11   lokomotor.mp. (0)
12   lokomat.mp. (3)
13   patterned electrical stimulation.mp. (1)
14   wheel.tw. (114)
15   (intensive adj rehabilitation).mp. (69)
16   activity based restoration.mp. (0)
17   coordination dynamics.mp. (13)
18   co-ordination dynamics.mp. (1)
19   project walk.mp. (0)
20   beyond therapy.mp. (2)
21   passive motion.mp. (185)
22   central pattern generat$.mp. (17)
23   ((intensive or therapeutic) adj exercise).tw. (151)
24   (exercise adj routine).tw. (10)
25   or/6-24 (8104)
26   5 and 25 (438)
27   limit 26 to human [Limit not valid; records were retained] (438)
28   letter.pt. (3707)
29   27 not 28 (434)
30   limit 29 to abstracts (352)
31   limit 29 to review (7)
32   30 or 31 (355)

33   limit 32 to english (344)

Cross database search of AMED, Cinahl, Medline, Embase

1   spinal cord injur$.mp. (26491)
2   immersion therapy.mp. (11)
3   "dardzinski method".mp. (0)
4   constraint induced therapy.mp. (156)
5   taub therapy.mp. (0)
6   forced therapy.mp. (1)
7   augmented feedback.mp. (67)
8   biofeedback.tw. (3493)
9   neuromuscular stimulation.tw. (425)
10   somatosensory stimulation.tw. (554)
11   circuit resistance training.tw. (20)
12   arm crank ergometry.tw. (51)
13   repetitive transcranial magnetic stimulation.tw. (1633)
14   or/2-13 (6392)
15   1 and 14 (186)
16   remove duplicates from 15

Current Contents and Science Citation Index

1. Parapleg* OR tetrapleg* OR quadripleg*
2. "Spinal cord injur*"
3. Exercise
4. (#1 OR #2) AND #3
5. #4 AND (therapeutic OR intensive)
6. Lokomotor OR lokomat OR treadmill OR wheel
7. Functional electric* stimulation OR patterned electric* stimulation
8. Activity based restoration OR coordination dynamics OR co-ordination dynamics
9. Project walk OR passive motion OR central pattern generat*
10. #4 AND (#6 OR #7 OR #8 oR #9)
11. #5 OR #10

12. Mice OR mouse OR rabbit*
13. Animal OR rat OR rats
14. #11 NOT (#12 OR #13)

Please note that the Current Contents database does not have subject indexing and therefore does not support the complexity of searching that is available on the other bibliographic databases

Cochrane Central Database of Clinical Trials

1. Spinal cord injur*
2. Exercise
3. #1 AND #2
4. Treadmill OR electric OR stimulation OR electircal OR electro*
5. Wheel OR intensive OR passive motion OR dynamics
6. (#4 OR 5) AND #1
7. #3 OR #6

Appendix 2: SIGN grading system

Levels of evidence

1++   High quality meta analyses, systematic reviews of RCT's, or RCT's with a very low risk of bias

1+   Well conducted meta analyses, systematic reviews of RCT's, or RCT's with a low risk of bias

1 -   Meta analyses, systematic reviews of RCT's, or RCT's with a high risk of bias

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2++   High quality systematic reviews of case-control or cohort studies
High quality case-control or cohort studies with a very low risk of confounding, bias, or chance and a high probability that the relationship is causal

2+   Well conducted case control or cohort studies with a low risk of confounding, bias, or chance and a moderate probability that the relationship is causal

2 -   Case control or cohort studies with a high risk of confounding, bias, or chance and a significant risk that the relationship is not causal

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3   Non-analytic studies, e.g. case reports, case series

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4   Expert opinion

Note: For this report, non-randomised comparative studies are classified as "2", with a 2+ given for high quality studies and a 2- allocated if there are significant methodological or reporting issues

Appendix 3: Study Tables
Body-weight-supported treadmill training (BWSTT) - RCT's
Key: Pw=pulsewidth; Hz=frequency in Hertz; Of=on/off cycle; Ud=up/down parameters; O=output; C=complete; I=incomplete; T=tetraplegia; P=paraplegia; BWS=body-weight support; AFO=ankle/foot orthosis

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Field-Fote et al 2005[25]	RCT 4 therapies "Stratified randomisation process based on pre-training Lower Extremity Motor Score Chronic injuries, all incomplete The paper begins by stating that treadmill training "improves overground walking ability in individuals with motor-incomplete spinal cord injury" and this paper aims to determine which method gives best results 1.BWS Treadmill training with manual assistance 2.BWS Treadmill training with stimulation to the	27 7 in the first 3 groups, 6 in the training with robotic assist Chronic individuals all > 1 year post-injury Damage above T10 level; patients needed to be able to take one step with one leg at least and arise from sit-stand with moderate assistance of one other person only	45 min walking, 5 days/week, 12 weeks ≤30% BWSTT otherwise customised to client Stimulation parameters to the peroneii; pw300-600msec, Hz=50, O=5-20mA	Training sessions varied from 30-54 across all groups 6m walk results (speed) Treadmill stimulation group and overground walking group showed statistically significant improvements from baseline to completion (p=0.02 and p=0.008) but not in the manual assist treadmill training group or Lokomat group. Greatest increases were seen in the overground and treadmill FES groups (.11-.175m/s and .14m/s -.19m/s) No differences were seen between the groups after the intervention 2 minute walk results (speed) All groups improved significantly from baseline to follow-up with the 2 minute walk; however, no differences between the groups were found. Greatest increase was seen in the treadmill FES group and the overground group also (.12-.16m/s	Not reported	Paper does not state if groups were balanced; raw data indicated significant differences at baseline which is not explained by the 'stratified random design' ; e.g. age, injury level, initial lower extremity motor score The intervention varied significantly in terms of session numbers Adverse events or barriers to programme adherence not reported No reporting re concealment allocation or blinding Treadmill training intervention appears

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

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	peroneii 3.BWS Overground training with stimulation to the peroneii 4.BWS Treadmill training with robotic assistance (Lokomat®)			and .115-.15m/s) Differences in training speed between groups indicated the OG group was significantly slower than for all other groups (p<0.005 for all groups however). No differences were seen between the treadmill based training groups All groups indicated that training speed was significantly better on completion of the regime Notably those patients that commenced the study with slower walking speeds improved the most over the course of the study Authors report that to identify between group differences 13 subjects per group were required with alpha level at 0.05 and power at 80%		substantial in terms of intensity frequency and duration Subjective Functional outcomes reported poorly in the discussion "Subjects consistently reported that the gains made meaningful difference to their daily function, enabling them to successfully perform activities they were previously unable to do…" Authors report that other assessments that were administered at the time e.g. balance, pulmonary function, quality of life and so on will be reported in ensuing reports. These have thus far not been identified from literature searching 1-

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

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Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Hornby et al 2005[54]	RCT (3 arms) • Robotic-assisted BWSTT (Lokomat®) • Therapist-assisted BWSTT • Overground ambulation with a mobile suspension system for safety and support Acute and post-acute phase, incomplete and incomplete injuries were included	N=35 Above T10 Time since injury 14-180 days ASIA classification B-D and required manual assistance of one to ambulate over ground	Up to 90 minutes walking/week, usually 3 x 30 min sessions Overground at variable speed customised to patients otherwise 2.0km/hr speed for robotic-assist training and therapist assisted BWSTT BWS varied between 25-78%; Max distance 3km/week for treadmill groups and limited only by training duration in the overground subgroup	N=30 completed 8 weeks (10 per group) Assessments performed two weeks prior to study and two-weekly thereafter BWS decreased to 0-78% at completion No significant differences between groups was seen with regards to Lower Extremity Motor Scale (LEMS), spasticity, sitting/standing balance, Functional Independence Measure (FIM) or Walking Index for Spinal Cord Injury (WISCI) at baseline; Post-training data indicated significant improvements in FIM, WISCI and LEMS (data graphed only). The paper does not report the raw increases from baseline to follow-up for each group. 5 subjects in each of the BWSTT groups could ambulate without physical assistance by the end of training No differences between groups with respect to recovery Patients entering the study with LEMS score of <10 improved with walking independence less than those that scored >10	Not reported	Includes some acute phase patients Limited information re study design and data reported in a limited way No explanation for the 5 losses to follow-up Adverse events not reported 1-

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Postans et al 2004[26]	RCT

Combined BWSTT with concurrent FES with acute and sub-acute incomplete injuries

4 week control (standard physiotherapy treatment) and 4 week intervention phases

Patients randomly assigned to control/intervention or vice-versa

Includes some patients treated in the acute phase of their rehabilitation | N=14, 12 male 4-23 weeks post-injury, mean=12.2 weeks 19-71 years All incomplete N=9 in acute post-injury period | Gait training with FES 5 days/week (max 17 sessions) Harness supported BWSTT 2x 2 channel stimulators delivered FES, triggered by footswitches. Commenced with 40% BWS. Subjects walked max 25 minutes/session.

Control treatment was standard physiotherapy 5 days per week (unspecified) | 3 day assessment period at the end of the 4 week intervention periods (washout period) 4 losses to follow-up AB= control followed by intervention BA=intervention followed by control

7/10 subjects that completed were >10 weeks post-injury Two withdrawals from study (unspecified) Two additional unable to complete assessments Results 5 patients per group only

Treadmill walking: Both groups AB and BA improved walking speed during treadmill phase Mean overall increase of .175m/s in AB group (p=0.001) and .145m/s in BA group at end of both treatment periods All but subject 14 saw a progressive decrease in BWS, 18.6% in AB and 21.8% in the BA group Overground walking (6 minute walk) AB group showed statistically significant improvements in walking endurance after control period (mean metres= 38.4; p=0.044) and treadmill training (mean metres=72.2, p=0.03) In the AB group speed, cadence and stride length were all also statistically significant from the end of the control to the end of the intervention period | Not reported | Note the number of subjects within the acute period – n=9

Substantial baseline data missing from raw data evident; this brings significant uncertainty into the statistical analyses

Very short washout period

Confusing reporting of results

Incorrectly described by authors as a crossover trial

Note no indication whether there was a significant improvement in *function* as a result of the overground improvements

Adverse events not reported

1- |

				(fewer steps per minute, increase in individual step length). BA group to the contrary only showed statistically significant improvements in walking distance after the control period (mean metres= 60.1,p=0.03); no other statistically significant changes were seen in the BA group in either control or intervention phases Mean increase in overground walking speed was .23m/s in AB and .17m in BA group after intervention		

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *66*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

BWSTT– non-randomised comparative studies

Author/Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Wernig et al 1998[10]	This publication reports on long-term (6 months-6.5 years) post hospital discharge where patients received initial conventional and Laufband training Non-randomised comparative study Effect of BWSTT Independent assessor Follow-up study to Wernig et al 1995 Evaluations undertaken 6 months-6.5 years following BWSTT training Chronic and acute incomplete injuries	N=76 Acute=41 Chronic=35 Enrolled T12 or above, including cervical injuries Chronic patients=6-15 years post-injury Acute=within a few weeks of injury 33 additional cases added from the previous report	See Wernig et al 1995	Chronic patients Of 25 wheelchair-bound patients, 5 remained so and 20 became independent Those independent before BWSTT, "usually remained within their original functional class" (2 improved), but all patients improved speed and walking endurance Histogram of results provided only Follow-up evaluations indicated improvements were "generally maintained". One patient deteriorated by one class and 3 improved one or two classes Acute patients N=41 8 still wheelchair-bound after BWSTT At long follow-up 6 remained wheelchair bound, fewer patients needed a walker and more could walk unassisted. None deteriorated	Not reported	Study includes some patients in the acute phase of treatment Descriptive report, no statistical analyses Note the variability in cases reported for 1995 and 1998 papers No details on losses to follow-up Adverse events not reported 2-

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Wernig et al 1995[9]	Non-randomised comparative study Compared BWSTT (acute and chronic patients) with "conventional therapy" group

12 of the chronic patients comprised a "temporal control" group; they had complete injuries that meant they had remained wheelchair bound following post-acute conventional therapy (5.5-8.5 months conventional; 8 of which followed the post-acute rehab immediately with Laufband therapy, 4 who entered 1-4.5 months after conventional therapy)

Independent evaluators of | N=89 BWSTT N=64 "conventional therapy" BWSTT group: Levels of injury not stated except for stating included cervical and thoracic

BWSTT group 44 chronic - .5-18 years since injury (median=1); 45 "acute" - " within a few weeks" of injury Chronic group had undergone prior bouts of conventional therapy (Thoracic level=10, cervical=2) In acute group, 13 subjects were below T10

Compared with 24 chronic and 40 acute conventionally treated; This group had prior conventional treatment | BWSTT 30 minutes 1-2x/day, 5 days/week Chronic patients received between 3-20 weeks of treatment Acute patients received between 3-16 weeks of treatment Therapist manual assistance with legs as required Customised body-weight support

Overground walking instituted "as soon as possible" concurrently with BWSTT and stair and outdoor walking introduced as able

Concurrent "conventional therapy" for BWSTT subjects also | 6/44 chronic patients omitted due to other types of spinal cord injuries Analysed a sub-group of the chronic group (n=29) that had incurred injury at least 1 year prior to the study

Walking abilities classified on the patient's ability to walk overground (0-5 scale, non-validated); initially walking distance rated over 5-10 metres, later ratings 100m

Voluntary muscle activity also assessed using an overall muscle function measure (sum of 8 lower limb muscle groups)

Chronic patients Locomotion ability improved in almost all of 44 subjects. Improvements seen in those patients that were wheelchair bound and walking at start of study. 6/44 able to staircase walk at study commencement improved to 34/44 at study end. Those patients ≥1 year post injury; 14/18 were able to walk after treadmill training, with 1/14 able to walk after conventional therapy

21 patients followed .5-3 years; 18 "continued to use fully their new abilities in their domestic surrounding and several | Not reported | "Similar levels of injury between control and treatment group" (no statistic report)

No ages or other baseline demographics for groups reported

locomotor ability scale likely not validated

Largely descriptive study; No statistical analyses performed for pre-post improvements or between sub-groups

Appears to be losses to follow-up in conventional chronic group (24>>14); this is not explained

2+ |

				reported further improvements in endurance" (29 BWSTT were compared with 24 chronic conventionally-treated patients) 14/18 wheelchair-bound patients learned to walk without assistance following BWSTT as opposed to 1/14 after conventional therapy		
	locomotor abilities Incomplete injuries Criteria to enter treadmill therapy: some voluntary muscle activity in lower limbs and "reasonable potential to use canes or other assistive devices"			Acute patients 36/45 wheelchair bound in the BWSTT group, 33 reached independence of assistance for walking as opposed to 12/24 that made significant improvement. No difference in voluntary muscle activity was seen between the groups (no statistic reported) Note EMG recordings were performed for 5 subjects		

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

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BWSTT - case series

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes			Level of Evidence/Conclusions
					Results	Adverse Effects	
Ferro et al 2007[36]	Case series BWSTT + NMES to quadriceps Specifically assessing impact of gait training on subjects' knees, and correlate clinical and radiological findings Chronic incomplete and complete injuries	N=9 ASIA A, n=5 ASIA B, n=2 ASIA D, n=2 All cervical lesions C4-7 Age range=25-46 yrs Time since injury=22-123 months	2 x 20 min sessions/week 30-50% BWS for 6 months NMES to quadriceps 5 months prior to commencing gait training Initially at 0.5km/hr 4 channel stimulator; Hz=25, pw=300m/sec; O=200V MRI of knees taken before and 6 months after commencement of training			Abnormalities "mild" at most Cases: 1. Grade 1 meniscus lesion progressed to Grade 3 2. contusion medial condyle, no clinical abnormality 3. Grade 2 lesion medial collateral ligament 4. Grade 3 lesion medial meniscus with some varus instability	Authors report difficulty in determining inevitable atrophy-related lesions from treadmill-related ones Debate acknowledged re the relevance of MRI in cartilaginous lesions 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *70*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence /Conclusions
				Results	Adverse Effects	
Wirz et al 2005[33]	Case series Multi-centre case series (5 units) using Lokomat® over 2 years Chronic incomplete injuries L1 injuries or above, >2 yrs post-injury; and patients needed to engage in lower limb standing and/or walking as part of everyday activities	N=20, 18 male 11T 9P Time since injury=2-17 years Age range=16-64 yrs, mean age=40 yrs	Up to 45 minutes/session, 3-5x/week, 8 weeks Gait speed up to a maximum of .66m/s BWS as low as possible No concurrent treatment	Mean session number=26 (24-37) Mean walking speed=0.55m/s (0.42-0.67m/s) Mean walked distance/session=1279m (200-1893m) Mean BWS=37% _WISCI II scores_ 2 subjects showed improvement only (p=0.22 for group) Speed increased (overground) on the 10-metre walking test in nearly all subjects (p<0.001) 6-minute walking test scores improved in 15/16 subjects, and as a group showed a significant improvement from baseline (p<0.001, mean increase 32.3m) "Timed –up-and-go" times reduced in all but 2 subjects (mean decrease in time=25s, p<0.001) The slower ambulators showed the greater relative improvement in walking ability _Lower extremity motor scale_ Scores improved by a mean average of 2.5 (p=0.016) but improvement did not correlate with other walking tests. Ashworth Scale scores also improved significantly from baseline but did not correlate with other ambulatory measures (p<0.01)	Not reported	Adverse events not reported 3

Author/ Yr	Design/ Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Hicks et al 2005 [31]	Case series Aged<60 Chronic incomplete injuries	N=14, 11 male Time since injury=1.2-24 years All incomplete C4-L1 All wheelchair dependent at study commencement Walking abilities assessed every 3 months, at end and 8 months following programme cessation Subjective measures administered every 36 sessions Patients that completed the programme were invited to attend once weekly BWSTT and/or twice weekly arm ergometry and resistance training Assessed: Walking speed Distance walked Subjective well-being using	3 bouts 10-15 min walks/session, 3 sessions/week until 144 sessions reached (approximately 12 months) Body-weight support commenced at ≥60%, speed ≤0.6km/hr; customised as patient progressed. Session length increased as tolerated	Age range=20-53 years Compliance with sessions ranged from 66.7-93.4% More than half of the participants did not become capable of walking (even with assistance); there were limited changes in overground walking ability from baseline to 12 months (4 patients improved♦) _Baseline to study end results_ Body-weight support significantly decreased (p<0.01) Walking speed increased 0.5-1.4km/hr (p<0.01) Distance walked increased 221.4-961.7m, p<0.01) Note BWS increased from study end to follow-up but was still significantly better than at baseline (p<0.01 for both); this was not correlated with adherence to a follow-up regime Life satisfaction increased (Satisfaction with life scale, p=0.05), Satisfaction with physical function increased (p=0.03); No improvement in CES-D scores, perceived health (SF-36) or perceived ability to perform Instrumental	One withdrawal 12 completed 8 month long-term follow-up	Reported results using intention-to-treat analysis as well as completers only Modified Wernig Scale used to classify walking capacity Adverse events not reported 3

♦ Modified Wernig Scale used for measuring functional walking in addition to distance, speed and body-weight support. Modified Wernig Scale;
0=No walking capability, even with help of two therapists; 1=Capable of walking<5 steps with the help of two therapists or along parallel bars; 2=Capable of walking≥5 steps with the help of two therapists or along parallel bars; 3=Capable of walking >1 length of the parallel bars, requiring assistance to turn; 4=Capable of walking >1 length of the parallel bars, turning independently; 5=Capable of walking along railing (<5 steps) with the help of one therapist; 6=Capable of walking along railing (>5 steps) with the help of one therapist; 7=Capable of walking with a rolling walking frame >5 steps; 8=Capable of walking with canes or crutches >5 steps; 9=Capable of walking without devices >5 steps.

	CES-D (depression scale) Life satisfaction Perceived health Modified Instrumental Activities of Daily Living Scale (IADL)		activities of daily living scale (IADL) Adherence to the follow-up BWSTT sessions offered was low (31.7%) (0-82.9%) and was lower for the combined BWSTT and fitness regime (22.5%; range 0-71.4%) Reduced satisfaction with physical ability was noted at long-term follow-up (p=0.03) unrelated to speed or BWS; no other indices changed in the follow-up period 20 month results indicated that subjects required greater BWS support than at the completion of the trial (p<0.02; 19.5-34.9% BWS) but that this was below pre-training values No changes in mean overground walking score were seen from end of study to 8 month follow-up (Modified Wernig Scale) Note, however that 7/14 participants commenced with a baseline of 0 on the wernig scale and did not prggress post-training or at final follow-up		

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Thomas and Gorassini 2005[32]	Case series Chronic incomplete patients BWSTT + manual assistance Assessed the specifics of the corticospinal tract function as well as functional changes following intervention Compared motor-evoked potentials with data from 5 able-bodied subjects and 6 non-trained SCI subjects	N=10, 8 male 29-78 years, mean 54.4 All incomplete ≥1 year post-injury with stable motor ability No orthoses were able to be worn during training Some subjects continued with overground training once or twice a week in the last 1-2 months of training. Training was stopped when WISCI II scores failed to improve	5 sessions/week – 1 hour duration, with manual assist as required 40-74 sessions	Mean sessions =4.1/week for 16.6 weeks BWS requirements reduced from 44.3% to 13.4% at completion of study All but one subject improved walking function (WISCII II scores increased from a mean baseline of 6.4-9.8 (p=0.027) MEP scores were significantly correlated with the absolute increase in WISCII II scores (p<0.05) 6-minute walk distance increased 34.2-167.7m (p<0.01) Overground walking speed (in the 4 subjects that were capable pre study) improved (18.8s post versus 62.6s pre) Two subjects measured 2.5 years after training maintained walking gains, with similar recruitment curves	Not reported	Non-blinded assessor Adverse events not reported 3

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Field-Fote & Tepavac 2002[35]	Case series Combined BWSTT with FES Assessed intra-limb coordination and overground and treadmill walking speeds Chronic incomplete injuries	N=14 (9 male), 3 able bodied (2 male) 9T 5P Levels of injury not stated Time since injury 12-171 months (mean=70 months) Age range 18-50; mean age=31 yrs; able bodied mean age=33.7 All incomplete	3 days/week, 3 months (36 sessions) over 12 weeks 1.5 hrs/day (patient determined rests/bouts times) Customised Body-weight support	Overground walking speed improved by an average of 84%, and treadmill walking increased on average 158% A moderate correlation was seen with walking speed and intra-limb coordination parameters (r=.75, no p value)	Not reported	Limited statistical analyses Limited information on assessments No adverse events reported 3

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Field-Fote 2001[30]	Case series BWSTT and FES Chronic incomplete patients	N=19, 13 male Time since injury=12-171 months, median =56 months Mean age 31.7 yrs 13T 6P All incomplete injuries Levels of injury not stated Patients must be able to rise from sit-stand, using upper extremity assistance and require no more than moderate assistance from one person; to stand upright with not greater than 30% body-weight support; and have a capable flexion withdrawal reflex at tolerable levels of electrical stimulation	1.5 hrs/day, 3 days/week, 3 months to a total of 36 sessions Stimulation parameters: Pw=1m/sec O=60-100V Of=500m/sec	Assessed overground walking speed without support and FES and recorded 2-minute walk (could use orthoses and assistive devices) times and distances Mean overground walking speed increased from 0.12-0.21m/s (p=0.0008) Treadmill walking speed increased from 0.23-0.49 (p=0.00003) Mean treadmill distance/session improved from 93-243m (p=0.000001) Lack of correlation between change in overground walking speed and change in treadmill walking speed Lower extremity motor scores increased a median of 3 points (15-18 in non-FES leg and 8-11 in FES leg, p<0.005 for both) Four subjects had long-term follow-up (2mths-1yr); 3 demonstrating overground walking speeds as 'good' or better' than those of their final evaluations. One subject deteriorated.	Not reported	No overall functional scores ? significance of change in LEMS scores of 3 points Adverse events not reported 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *76*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Wirz et al 2001[29]	Case series BWSTT Assessed EMG, force on treadmill footplates and mean action potentials	N=32 Time since injury 32-347 days C4-T12 C16 I14 One patient incomplete at L3 Complete subjects range= 14-53 years, mean age=35 Incomplete subjects range=13-72 years, mean age=35 (I)	300m treadmill walking, 1.5km/hr, 5 days/week Partially unloaded with BWS customised	Mean duration treadmill training complete injuries=148; for incomplete=125 Average training lasted 137 days After finishing locomotor training, all incomplete patients used their locomotor capability every day on normal ground conditions. All patients with complete injuries never performed stepping movements after locomotor training stopped	Not reported	Note some patients fall into the acute and post-acute period Almost absent functional reporting Adverse events not reported 3

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Colombo et al 1998[28]	Case series BWSTT with chronic injuries, complete and incomplete	N=12 C5, I7 Time since injury 49-323 days Unknown levels of injury Age not stated	BWSTT 300m, 1.5km/hr Manual assistance with up to 80% body-weight support Therapist-assisted leg movements as required	Complete patients: Reduction in body loading and increase in EMG activity over time. No significant change in ASIA scores Incomplete patients: Significant increase in EMG in stance phase and decrease in body unloading. No change in ASIA scores following training	Not reported	Unknown frequency and length of treatment Poor report in general with very limited information on methodology and results Adverse events not reported 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *78*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Neuromuscular Electrical Stimulation (NMS) Study tables - RCT's

Key: Pw=pulsewidth; Hz=frequency in Hertz; Of=on/off cycle; Ud=up/down parameters; O=output; C=complete; I=incomplete; T=tetraplegia; P=paraplegia; BWS=body-weight support; AFO=ankle/foot orthosis

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Aydin et al 2005[40]	Quasi-randomised Efficacy of TENS and oral Baclofen for spasticity 20 volunteers matched for age in order to compare H-reflex variables.	N=21 with problematic spasticity Excluded those with complications that can cause spasticity to increase e.g. heterotopic ossification or systemic disease that can cause peripheral neuropathy. Other exclusions included obesity.	Concomitant "exercise therapy, including range of motion" each morning for both groups Baclofen dose; 5mg increase every 3-5 days until adequate clinical response was achieved to a maximum of 80mg/day; divided into 3 oral doses TENS Bilateral tibial nerve stimulation; 50mA, Hz=100m, u/d=100msec 15 min sessions, 15x, once daily.	Baclofen=10 (all female,3T, 7P; mean age 32.7 yrs) TENS=11, 5 female; 2T, 9P; mean age 29.3 yrs Mean time post-injury 11.5 months both groups (range 2-49 months) Age and time post-injury non-statistically different between the groups (>0.05) Evaluated after 8 weeks (24 hours post completion of interventions) and for the TENS group, spasticity and other scores measured 15 minutes after first application and 15 minutes after 15th session. Weekly neurological examination Spasm frequency scale and spasm effect on pain and disturbance measured Clonus and muscle tone, Functional Disability Score and Functional Independence Measure (FIM) Functional independence measure H-reflex Baclofen pre and post treatment improved Ashworth score (p=0.011), spasm frequency scale (p=0.014), deep tendon reflex score (p=0.025), functional disability score (p=0.004) and FIM(p=0.005) TENS pre and post treatment improved spasm self-score, h-reflex parameters, FIM and FDS significantly (p=0.014, p=0.020-0.025, p=0.003 both) Significant improvements from baseline in both groups in	No muscle weakness in Baclofen group; dryness of mouth in 3 patients and fatigue in 2.	Randomised according to the duration required for evaluation No information re concealment allocation or full randomisation details Assessors blinded to other results but not to interventions Note patients received concurrent exercise therapy which may confound outcomes Improvements in FIM scores may have limited functional impact although indicated statistical significance. 1-

				spasticity, functional disability and FIM Non-statistically significant improvements between TENS and Baclofen at the completion of treatment (p>0.05). FIM scores improved from a mean of 67 to 75.7 in the Baclofen group and 68.5 to 76.2 in the TENS group.		

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

80

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions including SIGN grade
				Results	Adverse Effects	
Klose et al 1990[7]	RCT – quasi-randomised – cross-over trial Interventions administered in two consecutive 8 week blocks 1. Physical exercise therapy 2. neuromuscular stimulation (NMS) 3. electromyographic (EMG) biofeedback training	Chronic spinal cord injuries 18-45 years C4-6 N=43 All incomplete injuries "restricted randomisation process" to ensure that each group was similar in terms of level and degree of injury	3 days/week **Group 1**; emg biofeedback and ex therapy (n=10) **Group 2**; emg biofeedback and neuromuscular stimulation (n=10) **Group 3**; neuromuscular stimulation and exercise therapy (n=9) **Group 4**; 16 weeks of exercise therapy (n=10) Each group 8 males, excepting group 1 where n= 7 EMG and NMS applied to biceps, triceps, wrist extensors and flexors bilaterally Exercise therapy regime included upper limb strengthening, mat mobility, wheelchair skills, self-care training, transfer skills NMS=single channel; ; Hz=50; pw=300msec; O=0-150mA; EMG=Neuropath 4000	N=39 completed Non-statistically significant differences between groups for the first 8 week block (both biofeedback groups combined) However, significant improvements measured from baseline across all groups for mobility, self-care and left arm manual muscle grades for the 8 weeks of training (p<0.05) (right arm non-statistically significant) No raw data reported Authors state all mean scores improved across all outcome measures from baseline to 16 weeks – raw data not reported	Not reported	Small sample No raw baseline subject data or results data provided – therefore, it is difficult to have confidence in the conclusions Blinded assessor Restricted randomisation process affects between measures analyses Unknown intensity and duration of the thrice weekly training Inadequate description of randomisation method and no mention of concealment allocation Largely unvalidated outcome measures used and what the Functional status and functional disability scores are is in fact unclear No explanation of losses to follow-up 1-.

NMS - case series

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Wieler et al 1999[49]	Case series Subjects acted as own controls and were assessed with and without FES Compared outcomes of SCI and FES with TBI and FES with respect to walking speed after receiving FES treatment Subjects recruited from four Canadian centres	N=47 Time since injury=0-17 years, only 2 under 1 year Age range=15-50 Excluded lumbosacral injuries C1-T12 All incomplete SCI=31 CVA=8 Traumatic brain injury=1 Patients had used FES for walking for at least the previous 3 months All subjects could stand and all except one subject could walk to some extent without FES 3 subjects used a knee/foot/ankle orthosis, 5 an ankle/foot orthosis	Stimulation: 1-4 channels using Unistim, WalkAide or Quadstim – otherwise parameters not specified Stimulation "customised to patients' needs" in terms of frequency and muscles stimulated	N=40 7 drop-outs excluded from data analysis Cerebrally injured subjects (CIS) =57 years mean average age; SCI subjects=36 years mean average age; CIS subjects analysed at an earlier time post-injury (3 years as opposed to 6 years in the SCI group) "Total change in walking speed" = final walking speed with FES-initial walking speed without FES Also measured the 'training effect' which was the result of comparing the initial and final walking speeds without FES Results taken at start and end of treatment (up to 180 weeks) SCI subjects' speed increased 55% compared with 19% for CVA subjects Training effect highly significant (p<0.01) in the total and SCI groups, but not in the CVA subjects Training effect accounted for more than half the increase in walking speed.	No stimulation induced complications requiring significant intervention. Some suffered transient skin irritation	Note that the 'training effect' accounted for over half the improvement in walking speed which is the more relevant outcome when considering FES in an intensive outpatient or semi-residential programme No raw data on subjects training frequencies; FES was used in the community and assessment based in treatment centre No explanation regarding losses to the programme Cerebrally injured group (n=9) significantly older which may have

				(p<0.01), although, was not significant when the CVA subjects were compared with the SCI subjects Subjects that commenced with a speed >1m/s showed the greatest training effect (average increase of .25m/s) Overall group indicated that speed improved as a result of stride length rather than a reduction in step cycle time 23 subjects chose to continue with FES following study. Others discontinued amongst other reasons due to lack of time (n=4), perceived lack of progress (n=4). 70% of subjects overall totally agreed they could walk better with FES than without		confounded outcomes No quality of life or other functional measures considered 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *83*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

Author/ Yr	Design/ Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Brissot et al, 2000[44]	Parastep FES Case series	N=15 16-47 years 13C 2I 11 males 6-240 months post-injury All thoracic injuries All were required to have intact lower motor neurons T12-L1 and below Excluded those with severe spasticity	One session daily; Parastep, 6 channel FES Inpatients received one additional session of quadriceps stimulation Gait with a walker; some wore short AFO's	Total mean sessions=30 2 patients lost to follow-up; one of which Standing permitted when quads strength reached 3-4kg under electrostimulation 13/15 acquired independent ambulation (most within one month) Mean walking distance=52.8m+/-69m (range 2-350m) Average speed .15+/-0.14m/s 5/15 patients continued to use long-term, however, all using for physical fitness not functional ambulation Psychological outcomes Assessed using 'analog' scales (not stated) Physical self-concept scores improved by a mean of 3.8/10, and reported a marked improvement in self-esteem Social scale scores improved a mean of 2.2 only	One patient withdrew due to the pain of electrostimulation, one due to pressure sore Other reported adverse events: Transient ankle oedema (n=4) Back pain at dorsolumbar junction (n=4) Falls (n=4 in 3 patients) – all occurring post-discharge. One sustained a sacral fracture as a result	Unclear when final assessments undertaken;?40 months average although paper reports a mean total of 30 sessions per patient only Essentially unknown psychological and social outcomes 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *84*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Ladouceur & Barbeau 2000[48]	Case series FES and gait (non-treadmill)	N=14 25-48.9 years; average=33 years 1.8-19.1 years post-injury All incomplete Injury level range C5-L1 Maximal overground walking speed (MOWS) was measured with FES orthosis use (combined group) without FES (therapeutic), both with their ambulatory devices. The difference between combined and therapeutic scores determined the orthotic effect	Four-week adjustment period of patients to stimulators then asked to use FES assisted walking "as much as possible" Parameters: Used Quadstim for quadriceps and peroneal nerve stimulation; Unistem or MikroFES for single channel stimulation Parameters: Varied FES parameters although fixed frequency of 25Hz and PW of 150µs	Maximal overground walking speed (over 10m) significantly changed at end year 1 compared to baseline (combined and therapeutic ; 0.26m/s and 0.25m/s, p=0.0012 and p=0.0003) Increase in functional mobility seen at end of first year (p<0.000) Those that were community walkers at the time of study commencement showed the greatest increase 2 subject had no change with MOWS in the combined result Some results were up to 4 years. No maximum time frame stated Many subjects reduced their dependence on walking aids	Not reported	As improvements were seen similarly in the therapeutic group the authors concluded the improvements were due to central nervous system plasticity Unable to determine validity of functional mobility measure Improvements over time appeared to follow an exponential or linear pattern 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *85*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Klose et al 1997[39]	Case series "Parastep 1" brand FES gait stimulator Assessed walking and some anthropometric parameters	N=16; 13 male Mean age=28.4 yrs Mean time since injury=4.0 yrs All complete injuries between T4-11	6 channel stimulator; 3 x weekly sessions to a total of 32 sessions over 11 weeks Up to 3 "walks" per training session, with 15-20 minutes rest between walking trials Hz=24; pw=150msec; O=09-300mA Patients were required to be able to stand for 3 minutes using the Parastep system prior to commencing ambulation	Peak single trial distance range=12-1707 metres (p<0.001; Mean distance=334m

Duration of standing and walking=6-187 minutes (stat significant, p<0.001)

Pace, no raw data, p<0.001) compared to week 1 data Also assessed body density, body fat and lean bodyweight

Statistically significant increases in mean thigh girth and calf girth (p<0.001); lean tissue mean volume indicated a significant increase (p<0.001) | No adverse events | No functional outcome measures

Authors acknowledge the extreme variability in individuals' performances

3 |

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Gallien et al 1995[38]	Case series Parastep 1 ambulation system 6 channel stimulator Parameters as described in Klose et al Assessed walking and some cardiovascular parameters	N=13 11 male 17-42 years, mean 27 Time since injury 5-240 months Level of injury T4-10 Some outpatient some inpatient treatment due to some patients living far from research centre	32 sessions 3-5/week, each session lasting 2 hours Standing initiated when quadriceps strength reached 3.5kg Ambulation out of parallel bars was introduced once the patient was adept using bars and when patient could initiate steps independently	3 patients only reached 32 sessions Most subjects ended training before the 30th session Standing achieved between sessions 1-9 First walk with Parastep 0-24 sessions Max ambulation distance range=2-350m Max speed range=0-0.6m/s (mean 0.2m/s) Poorest performance seen in those that were the longest since injury Thigh perimeter mean improvement of 5cm Mean heart rate increase 41% Max increase in BP 40mmHg 12/13 patients became independently ambulatory with Parastep Eight of the 13 continued use after the treatment period; "Parastep used regularly at home is for exercise, not to increase functional ambulation"	Back pain (n=2) Ankle sprain (n=2) Calcaneal fracture (n=1) Sacral fracture from a fall (n=1) No technical failures	Note the authors report the aim is to use Parastep to exercise not to use to be independently walking 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *87*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Sloan et al 1994[46]	Case series Subjective functional improvements measured along with anthropometric data following FES cycling programme Complete or incomplete C5-12 lesions; patients needed to have upper body balance and some use of the upper limbs was required to be enrolled	N=12 Time since injury=2 months-11.5 yrs Age range=15-54 yrs Incomplete=11, Complete=1 C5-L1	Treatment period over two years Cycling time increased over time to 30 minutes/session, 3 x weekly for 3 months. Time and load adjusted for the individual Patients underwent concurrent standard physical rehabilitation regime Exercise load increased in 5N increments till managed 20 minutes without a load at 50-60 RPM for incomplete injuries and 30-40 RPM for complete injuries Stimulation parameters; 90mA max, Hz=25, pw=300ms	N=9 remained in programme for at least 3 months Strength increased significantly in quads (p<0.047) and biceps femoris only (p<0.013) Muscle area in quads and the total area showed significant increases p<0.002, p>0.005) No increase in bone mineral density in the two patients measured and in some parameters showed significant decreases All incomplete patients reported subjectively improved function and wellbeing after 3 months (no raw data). Spasm changes were variable (no raw data)	Two withdrawals due to increased spasm	No raw data for subjective functional increases 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m   *88*

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes	Level of Evidence/ Conclusions
				Adverse Effects	
Nash et al 1994[45]	Case series

Safety study

All screened for joint and general pathology prior to inclusion

Semi-blinded radiographic assessment | N=10
16-31 years, mean=26.9 yrs
Time since injury=0.5-13 years (mean 4.9 years)

All complete injuries

C3-T9 | Initially 1 month of quads muscle training with FES (Hz=40, pw=375 m/sec, pulse duration=375m/sec constant current) which was progressed over time. Patients had undergone FES cycling 2-3x weekly, 30 minutes session; 1.5-5.7 years duration of treatment (mean 2.6 years) | MRI scans indicated:
14 positive pathologic findings (6 attributable to one subject)
3 subjects had no pathologic findings whatsoever
MRI indicated one subject with bilateral avascular necrosis in the femoral heads; 3/10 subjects with hip joint effusions

Knee:
One subject with microfracture of medial femoral condyle
One subject with avascular necrosis of the distal femur, lateral femoral condyle and tibial plateau
One subject a focal infarct of the medial femoral condyle
One subject with osteochondral excavation of medial tibial plateau
One with minimal knee effusion
Three subjects with meniscal defect; one thinning of posterior cruciate, one other with fibre loss without tear
One subject with definite chondromalacia patella, one with findings suggestive of this | No pre-study MRI assessments undertaken

Results possibly better than for those that have not undertaken training; although a case series with no pre-morbid radiographic data is of limited use

Semi-blinded radiographic assessment

3 |

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

89

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Stein et al 1993[50]	Case series Assessed walking ability and cardiovascular parameters	N=10 Time since injury=2.5-10 yrs Age range=20-44 C2-T10 All capable of standing unassisted, with various walking capacities	Two subjects had an implanted stimulator and two had percutaneous wires for stimulation Surface stimulation was available either through 1 or 2 channels Appears patients were monitored over one bout of FES walking (several minutes)	Stimulation increased speeds in all subcutaneous stimulation subjects. Mean difference (surface and percutaneous) was 4m/min. Oxygen consumption in those subjects that could walk without FES, 4/5 showed a decrease in oxygen consumption with FES Two subjects only reported in detail (implanted stimulators)	Not reported	Implications of the modest change in walking speed may depend on the initial walking speed Poor data reporting of all subjects 3

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

90

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Yarkony et al 1990[51]	Case series FES for standing Restricted inclusion from 18-50 years No specific outcomes on benefits from intervention; study aim to assess the feasibility of FES for standing	N=25 Time since injury=1-13 years Age 18-47 Level of injury=C7-T11 All complete injuries	Initial protocol emphasised isolated quads stimulation to prepare for standing 2x 5 min sessions daily progressed to 2x 60-90 min sessions daily Alternate leg 5s stimulation Home protocol with this Patients then evaluated for standing Trained patients to use knee/ankle foot orthoses Standing done in the home with a standing frame	4 subjects withdrew All achieved standing with FES and frame Six were able to stand without manual assistance Six only were sufficiently independent to be able to stand at home (all T4-6 injury levels and used orthoses) Typically patients able to stand for several periods of 5-15 minutes/daily Home-standers continued for 6 months No other functional outcomes reported	No adverse responses to stimulation reported	No information as to why 4 patients withdrew from the study 3

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Kralj et al 1988[47]	Case series

Data from 26 incomplete subjects is not included in the raw data, and is summarised only | N=76
Incomplete=26; Complete=50
44 male – mostly between T4-11, although range C6-L1
Age range=11-48 years

Time post injury variable – 66% started study within 24 months of injury

Channels of stimulation varied from 2-6 | 8-16 weeks of treatment
Patients used and progressed walking aids as able

Intermittent stimulation sessions 30-60 minutes, stimulation trains of=4s
Pw= 0.3 m/seconds and Hz=20
FES standing training commenced when quads torque reached 30-50Nm with 4 channel stimulator
Walking began when 3-5 minutes of standing was tolerated | All T4-12 patients were able to stand using FES
Walking was achieved by 25 of the complete subjects T4-12
Most able to walk 100-200m
Patients use dropped off over 3 months of home use with 16 remaining ambulatory
Seven/25 mastered crutch walking
Standing time ranged from 5-60 minutes

"Many patients reported using the wheelchair attached folding frame with FES practical as it allowed them to free one hand and perform a manual task" | None reported | Limited reporting of functional abilities as a result of FES

Adverse events not reported

3 |

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   - -

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NMS – case reports

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes	Level of Evidence/Con clusions
				Adverse Effects	
Balmaseda et al 1987[52]	Case reports (n=2) Safety	Time since injury not stated (1) 37 years ; C5 (2) 30; incomplete L4/5;	applied to Biceps; reduced sensation in area stimulator used reduced sensation in area stimulator used	2 x oval burns 3x 4mm on medial forearm (anode placement) 4 x 3x5mm burns on leg when stimulating dorsiflexor muscles All wounds healed completely without further complication within one month Burns may be prevented by ensuring skin is clean, that the appropriate conducting material is used, and with a monitored repetition rate	Treatments poorly described 3

Biofeedback

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Outcomes		Level of Evidence/Conclusions
				Results	Adverse Effects	
Klose et al 1993[8]	RCT Stratified randomisation process based on level of injury "Aggressive" exercise therapy and neuromuscular stimulation =control group Compared with aggressive exercise therapy neuromuscular stimulation and biofeedback	N=31 Age range 19-30 yrs Baseline recordings at 6 weeks prior to study commencement, 6 weeks then 12 weeks after commencement Included only those that were >1 year post-injury C5-7 Required to have some bicep and deltoid contraction with gravity eliminated and no previous biofeedback experience No differences between groups at baseline in terms of functional ability or muscle strength	Randomised into Group A and B Both groups received exercise therapy for 45 minutes, 3x week for 12 weeks and neuromuscular stimulation (30 minutes/session, 3 x week) Exercise therapy consisted of strength, functional mobility and endurance training Trial intervention Biofeedback=30 minutes/session, 3x/week for 12 weeks using NeuroEducator EMG unit Subjects in the group without Biofeedback were in addition asked to voluntarily contract their muscles using the biofeedback protocol but without the auditory or visual biofeedback.	N=14 control (12 males) N=14 intervention 3 losses to follow-up Outcomes measured at 6 weeks and at the end of the 12 week programme Used modified ASIA motor index to grade muscle strength and a functional abilities measure (not specified) – score related to feeding, hygiene and dressing No significant differences between manual muscle test scores or functional activities scores were found between the groups at 12 weeks (p not reported) although both groups were statistically significantly better than baseline (both p<0.05)	Not reported	No reporting of blinding or concealment allocation Losses to follow-up not explained Unknown and likely unvalidated functional outcomes measure Adverse events not reported 1-

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s   *- -*

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Massed Practice Therapy

Author/ Yr	Design/Enrolment	Population/Inclusion, Exclusion Criteria	Intervention	Results		Level of Evidence/Conclusions
				Outcomes	Adverse Effects	
Beekhuizen et al 2005[6]	RCT Patients randomised to massed practice therapy or massed practice and somatosensory stimulation Unblinded assessor	Incomplete Cervical SCI Age range=16-70 yrs Minimum 1 year post-injury C7 injury or above Patients needed to have at least a trace of voluntary thumb movement	N=10 Interventions: 2 hrs per session, 5x per week for 3 weeks Treatment directed at the upper extremity having the lower motor score 5 categories of massed practice therapy; Gross upper extremity movement; grip; grip with rotation; pinch and pinch with rotation Each category had 10 tasks; order of categories was random; 25 minutes per block before progressing to the next category; random selection of tasks within categories Somatosensory stimulation: Simultaneously	1 female ASIA D, n=6 ACIA C, n=4 Mean age=39 years; range=22-63 Mean time post-injury=44 months Outcomes measured pre and at an unknown time post-treatment Measures: Pinch grip Functional testing: Wolf-motor function and Jebsen Hand Function Scores Transcranial magnetic stimulation Baseline measures balanced except for the difference in motor evoked potentials at baseline between the two groups (p=0.036) – unknown specific MEP's Significantly improved pinch grip in MP +SS group only from baseline to follow-up (p<0.05) MP +SS group showed a significantly greater increase in pinch grip strength than the MP group (p<0.05) Similar improvement pre to post in the MP	Not reported	Study design does not address the effect of massed practice with traditional therapy Unblinded assessor Very small sample No reporting of adverse events or interruption in the therapy procedures The therapy intervention is intense and whether this could be tolerated to or adhered to by patients is questionable 1-

A C C   E v i d e n c e   b a s e d   h e a l t h c a r e   t e a m

I n t e n s i v e   E x e r c i s e   P r o g r a m m e s   f o r   S p i n a l   C o r d - I n j u r e d   i n d i v i d u a l s - -

95

			administered with massed practice therapy; median nerve stimulation at wrist level for the entire 2 hrs of therapy Hz=1; 50=100microvolts; stimulus duration 1ms	+SS group for Wolf motor test and in favour of the MP +SS group when between groups analysis was performed post treatment (p<0.05) Jebsen scores improved in both groups post intervention follow-up (p<0.05); MP + SS group improved more than the MP alone (p<0.05) Pre and post-test MEP measures were unchanged in both groups from baseline (p=0.285 MP+SS and p=0.068, MP)		

Appendix 4: Injury Classification Systems

Frankel Scale[55]

(A) no function
(B) sensory only
(C) some sensory and motor preservation
(D) useful motor function
(E) normal

American Spinal Association Impairment Scale[56]

American Spinal Injury Association (ASIA) Impairment Scale

A= Complete: No motor or sensory function is preserved in the sacral segments S4-S5

B= Incomplete: Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5

C= Incomplete: Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.

D= Incomplete: Motor function is preserved below the neurological, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.

E= Normal: motor and sensory function is normal