ELECTRICAL STIMULATION AND SPASTICITY

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Andrews B.J., Bajd T., Roxendale R.H. (1988): TENS treatment of spinal spasticity. *Scand J Rehab Med Suppl* 17:155.

Apkarian J.A. and Naumann S. (1991) Stretch reflex inhibition using electrical stimulation in normal subjects and subjects with spasticity. J. Biomed. Eng 13, 67-73.
Abstract: The effect of electrically stimulating the tibialis anterior muscle on the stretch reflex of the soleus muscle in normal subjects and subjects with spasticity is investigated. Stimulation of the tibialis anterior just prior to the onset of a mechanical disturbance, which causes a stretch in the soleus, inhibits the stretch reflex of the soleus in normal subjects and may inhibit clonus in subjects with spasticity

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Bajd T., Gregoric M., Vodovnik L., and Benko H. (1985) Electrical stimulation in treating spasticity resulting from spinal cord injury. Arch. Phys. Med. Rehabil. 66, 515-517.
Abstract: To study the efficacy of electrical stimulation in treating spasticity of six spinal cord injured patients, transcutaneous electrical nerve stimulation (TENS) was applied to the dermatomes belonging to the same spinal cord level as the selected spastic muscle group. Spasticity was assessed in knee extensors by a pendulum test in which the knee joint angle of a swinging lower leg was recorded with an electrogoniometer. TENS was found to produce a noticeable decrease of spasticity in three of the patients, but had little effect on the others

Bajd T., Kralj A., Turk R., Benko H., and Sega J. (1989) Use of functional electrical stimulation in the rehabilitation of patients with incomplete spinal cord injuries. J. Biomed. Eng 11, 96-102.
Abstract: When patients enter the Rehabilitation Centre a therapeutic electrical stimulation programme is immediately initiated. Three groups of patients were identified: (i) those in whom an improvement of both voluntary and stimulated muscle force was observed, (ii) those with an increase in stimulation response only, and (iii) patients in whom no effect of electrical stimulation training could be recorded. Isometric measurement of voluntary and stimulated knee joint torque revealed that in a great number of patients one leg was severely paralysed while the other leg was under sufficient voluntary control. Unilateral two- channel stimulation of knee extensors and the peroneal nerve was proposed as an orthotic aid for this group of patients. Exaggerated extensor tone was observed by assessment of spasticity

around the knee joint. A two-channel peroneal stimulator was found to be a useful approach in order to inhibit this tone and thereby help the patients to initiate a step

Bajd T., Munih M., and Kralj A. (1999) Problems associated with FES-standing in paraplegia. Technol. Health Care 7, 301-308.
Abstract: Prolonged immobilization, such as occurs after the spinal cord injury (SCI), results in several physiological problems. It has been demonstrated that the standing posture can ameliorate many of these problems. Standing exercise can be efficiently performed by the help of functional electrical stimulation (FES). The first application of FES to a paraplegic patient was reported by Kantrowitz in 1963. It was later shown by our group that standing for therapeutic purposes can be achieved by a minimum of two channels of FES delivered to both knee extensors. The properties of the stimulated knee extensors (maximal isometric joint torque, fatiguing, and spasticity) were not found as sufficient conditions for efficient standing exercise. According to our studies, the ankle joint torque during standing is the only parameter which is well correlated to the duration of FES assisted standing. For good standing low values of the ankle joint torque are required. To minimize the ankle joint torque the lever belonging to the vertical reaction force must be decreased. Adequate alignment of the posture appears to be the prerequisite for efficient FES assisted and arm supported standing exercise. Some patients are able to assume such posture by themselves, while many must be aided by additional measures. At present, surface stimulation of knee extensors combined with some appropriately "compliant shoes" looks to be adequate choice

Bajd T., Kralj A., Stefancic M., and Lavrac N. (1999) Use of functional electrical stimulation in the lower extremities of incomplete spinal cord injured patients. Artif. Organs 23, 403-409.
Abstract: After a program of therapeutic electrical stimulation, 3 groups of incomplete spinal cord injured (SCI) patients were identified, those in whom an improvement of both voluntary and stimulated muscle force was observed, those with an increase in stimulation response only, and patients in whom no effect of electrical stimulation training could be recorded. As it is difficult to predict the outcome of the electrical stimulation rehabilitation process, a diagnostic procedure was developed to predict soon after accidents which incomplete SCI patients are candidates for permanent use of a functional electrical stimulation (FES) orthotic aid. The candidates for chronic use of FES are patients with weak ankle dorsiflexors and sufficiently strong knee extensors. These patients are equipped with a single channel peroneal stimulator augmenting dorsiflexion and knee and hip flexion in a total lower limb flexion response. By applying FES to the ankle plantar flexors, the swing phase of walking can be significantly shortened and faster walking obtained

Baker L.L., Yeh C., Wilson D., and Waters R.L. (1979) Electrical stimulation of wrist and fingers for hemiplegic patients. Phys. Ther. 59, 1495-1499.
Abstract: Passive cyclical electrical stimulation was applied during a four-week treatment program to the wrist and finger extensors of 16 hemiplegic patients with flexor spasticity. The study noted the effects of this treatment on the patients' sensation; spasticity; passive range of motion of the wrist, metacarpophalangeal, and proximal interphalangeal joints; and strength in the wrist extensor muscles. Patients were divided into chronic and subacute groups. Both groups received electrical stimulation for three half-hour periods a day, seven days a week, as a substitute for all other range-of-motion techniques. Flexion contractures were prevented in the

subacute group of patients at the wrist, metacarpophalangeal, and proximal interphalangeal joints. A statistically and clinically significant increase in wrist extension range occurred in the chronic group that had wrist flexion contractures before the electrical stimulation. Increased extension was noted at the metacarpophalangeal and proximal interphalangeal joints of patients in the chronic group. Those patients with some voluntary wrist extension before the treatment began were able to increase their extension strength during stimulation. No changes in skin sensation were noted and only a general trend in decreasing spasticity was apparent

Baker L.L., Parker K., and Sanderson D. (1983) Neuromuscular electrical stimulation for the head-injured patient. Phys. Ther. 63, 1967-1974.
Abstract: Recent research has shown that electrical stimulation is effective in treatment programs designed to maintain or gain range of motion, to facilitate voluntary motor control, and to strengthen muscles weakened by disuse. All of these treatment goals are relevant to the head- injured patient who frequently demonstrates profound disuse atrophy, joint contractures with excessive muscle tone, and decreased voluntary motor capabilities. As the cognitive status of the head-injured patient improves, electrical stimulation can be incorporated into traditional treatment programs to enhance their effectiveness. This article discusses using neuromuscular electrical stimulation with programs aimed at managing contractures, reducing spasticity, and facilitating voluntary motion. The limitations of electrical stimulation in the head- injured patient population are addressed

Bates J.A. (1978) Therapeutic electrical stimulation. The transistorized placebo? Electroencephalogr. Clin. Neurophysiol. Suppl 329-334.
Abstract: (1) Electrical stimulation therapy for patients suffering with labile signs and symptoms, and these include all varieties of acute and chronic pains, seizures and spasticity, has come into fashion and gone, and come again with each new technological advance for the past two hundred years. (2) A proportion of patients with chronic disease have their suffering made worse if they feel deprived of the latest therapy and may be relieved if they are given it in the right circumstances. In this group the relief will usually be temporary and the limited supply of such reactors will promote the cycle of fashion. In a group of 126 patients with chronic pain associated with organic disease who were offered transcutaneous stimulation, only 23 (18%) continued to use it one year after they started. (3) The cycling of therapeutic fashion is assisted not only because relief is often temporary, but also by the difficulty in establishing the normal range of variability from which significant change can be assessed and by the uncertain relationship between signs and symptoms and for the functions of daily living. For these reasons there is an inevitable tendency to temporary over- optimism and it seems impossible to counter this by the execution of a satisfactory clinical trial, since the patient cannot be "blind" and a significant variable is the enthusiasm with which a therapy is surrounded. (4) Electrical stimulation by cutaneous devices or implants can give much benefit to some patients in whom other methods have failed and there are indications, not only from anecdote and clinical impression but also now from experimental physiology, that it may benefit by mechanisms of interaction at the first sensory synapse. It is, however, an over-simplification to regard any therapy as either strictly physiological or simply fraudulent. Like other so-called placebos, physical methods of therapy can presumably act on hormonal systems associated with stress and the experience of pain

Barolat-Romana G., Myklebust J.B., Hemmy D.C., Myklebust B., Wenninger W. (1985) Immediate effects of spinal cord stimulation in spinal spasticity. *J Neurosurg* 62, 558-562.

Benecke R., Conrad B., Meinck H.M., Hohne J (1983) Electromyographic Analysis of Bicycling on an Ergometer for Evaluation of Spasticity of Lower Limbs in Man. In: Desmedt J.E. [Ed]: *Motor Control Mechanisms in Health and Disease.* New York, Raven Press, pp 1035,1046.

Benzel E.C., Barolat-Romana G., and Larson S.J. (1988) Femoral obturator and sciatic neurectomy with iliacus and psoas muscle section for spasticity following spinal cord injury. Spine 13, 905-908.
Abstract: The treatment of severe refractory spasticity following spinal cord injury may raise challenging therapeutic problems. Classical approaches involve various types of myelotomies, rhizotomies and intrathecal injections of neurolytic substances. Alternative approaches include percutaneous rhizotomies and, more recently, the possible use of electrical stimulation of the spinal cord. Certain cases, however, may not be amenable to commonly accepted techniques. An operative technique is presented which involves a suprapubic incision for an infraperitoneal approach to a femoral and obturator neurectomy and an incision of the iliacus and psoas muscles bilaterally. This may be followed, when indicated, by a bilateral infragluteal section of the sciatic nerves. This technique offers a viable surgical alternative to the treatment of spasticity following spinal cord injury in cases where other traditional methods are contraindicated or have failed

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Bhakta B.B. (2000) Management of spasticity in stroke. Br. Med. Bull. 56, 476-485.
Abstract: Spasticity treatment must be considered in relation to other impairments with functional goals defined prior to intervention. The effects of muscle co-contraction and involuntary limb movement associated with exaggerated cutaneous reflexes or effort as well as stretch reflex hyperexcitability need to be considered. Exacerbating factors such as pain must be identified. Physical therapy and conventional orthoses are the mainstays of spasticity management during acute rehabilitation. Botulinum toxin shows promise but needs further evaluation in the context of acute rehabilitation. Phenol chemodenervation can produce good results in spasticity refractory to standard treatments. Muscle strengthening exercises may be appropriate in chronic hemiparesis without adversely affecting tone. Electrical stimulation may be a useful adjunct to other spasticity treatments. Difficulty demonstrating functional benefit from antispasticity treatment may imply that interventions directed at single motor impairments whether weakness or spasticity are not likely to result in functional benefit, but it is their combination that is important

Billian C. and Gorman P.H. (1992) Upper extremity applications of functional neuromuscular stimulation. Assist. Technol. 4, 31-39.
Abstract: Functional electrical stimulation (FES) has been used for increasing muscle strength, decreasing spasticity, and controlling movement of limbs for many years. Most of this work, however, has been done in a research setting. Over the past decade, FES has moved slowly from the laboratory to the clinical world through feasibility studies in groups of patients with spinal cord injuries and strokes. Electrical

stimulation has been shown to decrease spastic tone both during and after the stimulation, allowing for better limb positioning, decrease in contracture formation, and in some cases, improvement of voluntary movement. Electrical stimulation as a motor prosthesis is now being provided to small groups of spinal cord-injured patients (primarily C4, C5 and C6 levels) to assist with hand positioning and to produce hand grasp. In these settings, patients have attained greater independence in activities of daily living and in work-related tasks. Distribution of this technology to multiple centers is continuing through a technology transfer program

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Botte M.J., Bruffey J.D., Copp S.N., and Colwell C.W. (2000) Surgical reconstruction of acquired spastic foot and ankle deformity. Foot Ankle Clin. 5, 381-416.
Abstract: With the aging population and improved methods of emergency transport, the number of surviving stroke and brain injury patients continues to increase. Aggressive rehabilitation of appropriate candidates is justified. In the period of spontaneous recovery, efforts are made to prevent fixed contractures using passive mobilization, splinting, nerve blocks, and electrical stimulation. If deformity persists and the patient is no longer recovering, operative management can help alleviate the functional and hygiene problems associated with these limb deformities

Braun Z., Mizrahi J., Najenson T., and Graupe D. (1985) Activation of paraplegic patients by functional electrical stimulation: training and biomechanical evaluation. Scand. J. Rehabil. Med. Suppl 12, 93-101.
Abstract: A training method for the activation of the lower limb muscles of paraplegics by functional electrical stimulation (FES) for standing and walking is described. It consists of a daily program which does not interfere with the normal routine of the patient. The treatment of four patients, paralysed form 7 to 30 years, is described. In these patients, a good standing position was achieved by stimulating the quadriceps, sometimes supplemented by the gluteus maximus or medius muscles. Gait was obtained by activation of the flexion reflex in a single stimulation and by tilting the trunk. Difficulties during gait were encountered due to the strong adduction of the legs. No mechanical support was required for locking of the lower limb joints. However, to maintain the equilibrium of the body, external support such as parallel bars, walker or Canadian crutches were used. During treatment gait improved due to reduction of spasticity and better stability of the body. Biomechanical measurements of weight bearing on the legs indicated values ranging between 41 to 65% of the body weight. During gait, a steady improvement of velocity was noted, with a parallel decrease in stance and stride times

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Burridge J., Taylor P., Hagan S., and Swain I. (1997) Experience of clinical use of the Odstock dropped foot stimulator. Artif. Organs 21, 254-260.
Abstract: The Odstock dropped foot stimulator (ODFS) is a simple functional electrical stimulation (FES) device for the correction of dropped foot. Improved reliability, fine control of stimulation parameters, and careful application and follow-up have let to 86% compliance. Data on 56 patients (50 patients with hemiplegia, 5 patients with multiple sclerosis, and 1 patient with spinal cord injury) who have used the system for between 6 and 18 months are presented and show a statistically significant increase in walking speed with the stimulator at 3 months of 14% ($p < 0.001$); decreased effort of walking, measured as physiological cost index (PCI), of 37% ($p < 0.001$); and statistically significant improvement in functional mobility tests and questionnaires. No statistically significant carryover was seen although 3 patients had sufficient improvement in active ankle control and gait parameters to no longer need the stimulator. Six patients who used the stimulator all day every day had a problem with skin irritation, which we have not yet been able to solve. Two patients discontinued use after experiencing increased spasticity in the calf

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Campos R.J., Dimitrijevic M.M., Faganel J., and Sharkey P.C. (1981) Clinical evaluation of the effect of spinal cord stimulation on motor performance in patients with upper motor neuron lesions. Appl. Neurophysiol. 44, 141-151.
Abstract: The effect of chronic electrical stimulation of the spinal cord was evaluated in a group of 24 patients with multiple sclerosis, spinal cord injury, and degenerative disorders of the central nervous system. The systems for stimulation had been implanted from 12 to 30 months prior to completion of evaluation. At the time of completion of evaluation, 23 of the 24 patients still had implanted systems, although 6 of them had not used spinal cord stimulation because of no noticeable effect. In 3 patients stimulation had been disconnected because of technical failure of the system. In 1 patient the system had been removed 8 weeks after implantation because of inflammation in the under- skin receiver pocket. The effects on motor performance of the remaining 14 patients who had continuously active systems were improved bladder control, diminished spasticity, improved movement coordination, and increased endurance

Carlsson C.A. and Fall M. (1984) Electrical stimulation of the conus medullaris for bladder emptying in a paraplegic. Paraplegia 22, 87-91.
Abstract: Nashold et al. (1972) have developed a surgically implantable system for activating the micturition reflex in the paraplegic by electrical stimulation of the spinal cord at the conus level. This communication describes the long-term course in a paraplegic patient who has used conus stimulation to achieve bladder emptying for 7 years. A 42-year- old man sustained a complete transverse lesion at the C6 level. Ten months after the accident he developed some spasticity in his legs but his urinary bladder remained completely flaccid. A device for electrical stimulation of the conus was implanted. This enabled the patient to empty his bladder without significant residual urine. His bladder remained flaccid. Seven years after the implant he developed reflex micturition and he is no longer dependent upon electrical stimulation

Carmick J. (1995) Managing equinus in children with cerebral palsy: electrical stimulation to strengthen the triceps surae muscle. Dev. Med. Child Neurol. 37, 965-975.
Abstract: A new therapeutic proposal for the management of equinus in children with cerebral palsy is to strengthen the calf muscles instead of weakening them surgically. Prior research indicates that in children with cerebral palsy the triceps surae muscle is weak and needs strengthening. Neuromuscular electrical stimulation (NMES) was used as an adjunct to physical therapy. A portable NMES unit with a hand-held remote switch stimulated an active muscle gait cycle. Results are discussed for four children, who showed improved gait, balance, posture, active and passive ankle range of motion, and foot alignment. The toe walkers became plantigrade and the equinovalgus posture of the foot decreased. Spasticity did not increase

Carmick J. (1997) Use of neuromuscular electrical stimulation and [corrected] dorsal wrist splint to improve the hand function of a child with spastic hemiparesis. Phys. Ther. 77, 661-671.
Abstract: This case report describes a program for a child with spastic hemiparesis who had previously received physical therapy with neuromuscular electrical stimulation (NMES). After a year without physical therapy, he returned to continue to receive NMES to strengthen muscles, increase sensory awareness, and improve

hand function. The child quickly regained his previous level of functioning and made additional progress. After 38 sessions, he still lacked adequate wrist stability for independent hand function. A dorsal wrist splint was used to stabilize the wrist while NMES facilitated muscle activity of the hand and wrist. While wearing the splint, the child could use his hand independently without adult interference or "assistance," thus allowing motor learning to occur. After 24 additional sessions (i.e., 9 months of using the splint), the child could use the hand for activities such as tying his shoelaces without the splint. No increase in spasticity was seen in spite of strengthening the spastic finger flexors

Carnstam B., Larsson L.E., and Prevec T.S. (1977) Improvement of gait following functional electrical stimulation. I. Investigations on changes in voluntary strength and proprioceptive reflexes. Scand. J. Rehabil. Med. 9, 7-13.
Abstract: Patients with central spastic paresis and equipped with peroneal stimulators sometimes experience an improvement in their gait, even when the stimulator has been switched off. The object of the present investigation was to reach a better understanding of the mechanisms operating in such cases. 7 patients were investigated on repeated occasions. It was found that some of these patients got a clear increase in isometric strength of foot dorsiflexion following 10 min of peroneal stimulation. In other cases the increase was only slight. There was an inverse relation between the increase and the strength before stimulation. The increase of strength was due, at least partly, to an increased ability to activate the foot dorsiflectors, since there was a simultaneous increase in the EMG from the anterior tibial muscle. Evidence was also obtained suggesting that the increase in strength involved not only foot dorsiflexion but also plantarflexion of the foot end extension of the knee. Following peroneal stimulation there was also a decrease of the achilles reflex and in some cases possibly also the patellar reflex. There was an inverse relation between the decrease in the achilles reflex and its strength before stimulation. It is probable that the changes in voluntary strength and reflex activity reflect conditions which can be of importance in explaining the gait improvement which is sometimes observed in patients equippped with peroneal stimulators

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Cooper I.S., Upton A.R., and Amin I. (1982) Chronic cerebellar stimulation (CCS) and deep brain stimulation (DBS) in involuntary movement disorders. Appl. Neurophysiol. 45, 209-217.
Abstract: Motor disorders of disinhibition may be modified by prosthetic mobilization of CNS inhibitory mechanisms by chronic electrical stimulation of the cerebellar cortex (CCS) and by deep brain stimulation of the thalamus and internal capsule (DBS). Reduction in spasticity, abnormal movements, intractable epilepsy and aggressive behavior has been reported after CCS, although negative results in human and animal studies have been published. No adverse neurologic, psychologic or intellectual effects of stimulation have occurred after 7 years of CCS, although subclinical histological changes may occur in the cerebellar cortex under the electrodes. CCS has been shown to produce physiological changes in evoked potentials, motoneurone excitability, epileptic discharges in the EEG and quantitative changes in movement. Surface and deep thalamic recordings have shown reduced amplitudes of somatosensory responses after CCS. Over the last 2 years we have employed chronic deep brain stimulation (DBS) in 49 patients with clinically useful results in half the patients. The technique allows reversible modification of movement

disorders, and the technique can be used on the second side after a previous thalamectomy. Physiological testing, direct thalamic recordings and quantitative analysis of movement have allowed assessment of optimal rate and voltage of stimulation. For some intractable movement disorders DBS has effected significant therapeutic results when all other therapeutic techniques have failed

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Daly J.J., Marsolais E.B., Mendell L.M., Rymer W.Z., Stefanovska A., Wolpaw J.R., and Kantor C. (1996) Therapeutic neural effects of electrical stimulation. IEEE Trans. Rehabil. Eng 4, 218-230.
Abstract: The use of a functional neuromuscular stimulation (FNS) device can have therapeutic effects that persist when the device is not in use. Clinicians have reported changes in both voluntary and electrically assisted neuromuscular function and improvements in the condition of soft tissue. Motor recovery has been observed in people with incomplete spinal cord injury, stroke, or traumatic brain injury after the use of motor prostheses. Improvement in voluntary dorsiflexion and overall gait pattern has been reported both in the short term (several hours) and permanently. Electrical stimulation of skin over flexor muscles in the upper limb produced substantial reductions for up to 1 h in the severity of spasticity in brain-injured subjects, as measured by the change in torque generation during ramp-and-hold muscle stretch. There was typically an aggravation of the severity of spasticity when surface stimulation reached intensities sufficient to also excite muscle. Animals were trained to alter the size of the H-reflex to obtain a reward. The plasticity that underlies this operantly conditioned H- reflex change includes changes in the spinal cord itself. Comparable changes appear to occur with acquisition of certain motor skills. Current studies are exploring such changes in humans and animals with spinal cord injuries with the goal of using conditioning methods to assess function after injury and to promote and guide recovery of function. A better understanding of the mechanisms of neural plasticity, achieved through human and animal studies, may help us to design and implement FNS systems that have the potential to produce beneficial changes in the subject's central nervous systems

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Abstract: We studied the effects of electrical stimulation of the skin on upper extremity spasticity in nine hemiparetic stroke subjects. The effects were quantified by comparing reflex torque responses elicited during ramp and hold angular perturbations of the elbow recorded before and after low-intensity skin stimulation. Electrical stimulation was applied to skin over the biceps muscle for a period of ten minutes at a 20 Hz frequency, pulse duration 0.1 ms, with an intensity level below motor threshold but above sensory threshold. In seven of the nine subjects, stimulation of skin over spastic muscle reduced peak torque responses in both flexors and extensors for at least 30 min. In these seven subjects there were significant increases in mean threshold angle for the onset of reflex torque so that a greater angular rotation was required to initiate the stretch reflex response. This shift occurred without change in reflex impedance. The origins of these long-term changes in reflex torque are unclear, but may reflect synaptic plasticity of spinal circuitry outside the stretch reflex loop

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Abstract: The effects of whole-hand electrical stimulation via a wired mesh-glove upon the residual motor control of the upper extremity are described. Clinical observations were made in 2 patients with nonfunctional upper limbs, 4 and 2 years after stroke, who had been enrolled in the home mesh-glove program for 6 and 4 months, respectively. The stimulation paradigm is novel and the target of stimulation is the hand. Preliminary results indicate beneficial effects such as reduction in muscle hypertonia and facilitation of isolated hand movements

Dimitrijevic M.R. and Sherwood A.M. (1980) Spasticity: medical and surgical treatment. Neurology 30, 19-27.
Abstract: Electromyographic (EMG) recordings from multiple muscle groups with surface electrodes during systematic evaluation of phasic and tonic stretch reflexes, cutaneomuscular reflexes, long loop reflexes, postural reflexes, and volitional activation have been used to provide a neurophysiologic basis for selection of the appropriate treatment for spasticity, and to gain further insights into the general mechanisms of spasticity. Pharmacologic methods are useful as a temporary measure. Hypertonia of a single muscle can be effectively treated with 40% alcohol injections to the motor points and hypertonia of a muscle group with partial denervation through 6% phenol in water injected into the nerve trunk. Hypertonia of several muscle groups can be treated by chemical or surgical rhizotomy or myelotomy. Generalized hypertonia involving limb and trunk muscles can be modified through chronic epidural stimulation of the spinal cord. Modification of

reciprocal antagonistic muscle activity may be achieved through electrical stimulation of the involved nerve trunks

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Abstract: Patients with dystonia, spinocerebellar and cerebellar ataxia and spasmodic torticollis have a reasonable chance of being significantly aided in their control of motor function and neurogenic bladder by electrical stimulation of the cervical or thoracic spinal cord. This mode of therapy has the advantages that it is not destructive of neurological tissue, effects can be varied by altering the intensity and rate of the stimulus and preliminary testing with externalization of the electrodes is predictive of the effects of chronic stimulation

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Abstract: We present the results and the methodology of trials using transcutaneous electrical stimulation. The aim of our work was to decrease spasticity in 44 patients with traumatic damage to the spinal cord; 35 non-electrically stimulated spastics were used as controls. Both groups were randomly selected from inpatients in the Paraplegic Department at the Hospital Rehabilitation Centre. This electrical stimulation procedure leads to a long-lasting reduction in spasticity, an increased range of passive and active movements, the facilitation of lost functions, an improvement in breathing, an increase in pulmonary capacity, the reappearance of some neurological reflexes, and a diminution of supersensitivity to skin irritation. Blood pressure and neurogenic bladder functions were restored to normal. In addition to clinical observations, we investigated muscle force and the electromyogram; other measurements used in the trials involved the use of a specially adapted neurological hammer, a pendulum test, spirometry, cystometry, sphincterometry and biochemical estimations

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Abstract: Spastic dysphonia, a rare speech disorder, is characterized by strained

phonation with excessively adducted vocal cords. Recurrent laryngeal nerve section, botulinum toxin injection into the vocalis- thyroarytenoid muscle complex, and other techniques have been used to treat this disorder. We have used percutaneous electrical stimulation of the recurrent laryngeal nerve with good results. Previous dog studies demonstrated the relative safety of an implantable recurrent laryngeal nerve stimulator. In this study, we directly stimulated the recurrent laryngeal nerve and vagus nerve in a dog without change in cardiorespiratory status. A Medtronic peripheral nerve stimulator was implanted in a patient with abductor spastic dysphonia. The cuff electrode was positioned around the recurrent laryngeal nerve and stimulation resulted in improvement in her voice. Extensive cardiopulmonary monitoring did not reveal any adverse response to stimulation and there was no discomfort to the patient. On the basis of the good results of this preliminary study, further study with long- term follow-up is under way

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Abstract: Spastic or hyperreflex bladder dysfunction can cause frequency, urgency, and incontinence. Detrusor activity was inhibited by FES (functional electrical stimulation) applied to the anal sphincter causing decreased bladder spasticity and increased bladder capacity. FES is indicated for incontinence not only because of weakness of the pelvic floor but also because of hyperreflex bladder

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Abstract: Electrical stimulation of the spinal cord (SCS) to reduce spasticity was evaluated in seven patients who, along with their physicians, perceived significant and prompt benefit from stimulation. In two 24- hour test periods, on or off stimulation, we used two independent methods of evaluation: quantitative measures of joint compliance and stretch reflexes, and a standardized neurologic examination. Neither method did better than chance in determining whether SCS was actually being received. Problems with the experimental protocol are discussed, but the results cannot be interpreted as supporting the efficacy of SCS as a treatment for spasticity

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Gracanin F. (1978) Functional electrical stimulation in control of motor output and movements. Electroencephalogr. Clin. Neurophysiol. Suppl 355-368.
Abstract: In patient with damaged upper motor neurones we show the therapeutic effect of electrical stimulation (called FES) of peripheral mixed nerves on the restoration of motor activity and movements. The results of neurophysiological, kinesiological and clinical observations are presented. We discuss the possible mechanisms, especially the spinal ones, which are fundamental for such a rhythmic activity as gait. We discuss them also from the point of view of activation of proprioceptive feedback mechanisms and of achieved sensory reinforcement influencing the spinal reflex mechanisms as well as the preserved supraspinal integrated activity which contributes to the long- term FES effect. The stimulation modes, the control of stimuli in relation to the needs of individual patients (hemiplegia in adults, paraparesis, cerebral palsy in children and multiple sclerosis) as well as the motor deficit are discussed. We conclude that the electronic system used for this purpose represents a functionally active orthotic aid with therapeutic effects

Granat M.H., Ferguson A.C., Andrews B.J., and Delargy M. (1993) The role of functional electrical stimulation in the rehabilitation of patients with incomplete spinal cord injury--observed benefits during gait studies. Paraplegia 31, 207-215.
Abstract: The benefits of a functional electrical stimulation (FES) gait programme were assessed in a group of 6 incomplete spinal cord injured subjects. Measurements were made of quadriceps spasticity, lower limb muscle strength, postural stability in standing, spatial and temporal values of gait, physiological cost of gait and independence in activities of daily living. The subjects were assessed before commencement of the programme and after a period of gait training using FES. The benefits derived as a result of the FES gait programme included a reduction in quadriceps tone, an increase in voluntary muscle strength, a decrease in the physiological cost of gait and an increase in stride length

Graupe D. and Kohn K.H. (1998) Functional neuromuscular stimulator for short-distance ambulation by certain thoracic-level spinal-cord-injured paraplegics. Surg. Neurol. 50, 202-207.
Abstract: BACKGROUND: Functional Neuromuscular Stimulation (FNS) for unbraced short-distance ambulation by traumatic complete/near-complete T4 to T12 paraplegics is based on work by Graupe et al (1982), Kralj et al (1980), Liberson et al (1961), and others. This paper discusses methodology, performance, training, admissibility criteria, and medical observations for FNS-ambulation using the Parastep-I system, which is the first and only such system to have received FDA approval (1994) and which emanated from these previous works. METHOD: The Parastep system is a transcutaneous non-invasive and microcomputerized electrical stimulation system built into a Walkman-size unit powered by eight AA batteries that is controlled by finger-touch buttons located on a walker's handbars for manual selection of stimulation menus. The microcomputer shapes, controls, and distributes trains of stimulation signals that trigger action potentials in selected peripheral nerves. Walker support is used for balance. The patient can don the system in under 10 minutes. At least 32 training sessions are required. RESULTS: Approximately 400 patients have used the Parastep system, essentially all achieving standing and at least 30 feet of ambulation, with a few reaching as much as 1 mile at a time. Recent literature presents data on the medical benefits of using the Parastep system-beyond the exercise benefits of short distance ambulation at will-such as increased blood flow to the lower extremities, lower HR at subpeak work intensities, increased peak

work capability, reduced spasticity, and psychological benefits. CONCLUSIONS: We believe that the Parastep FNS system, which is presently commercially available by prescription, is easily usable for independent short-distance ambulation. We believe that its exercise benefits and its other medical and psychological benefits, as discussed, make it an important option for thoracic-level traumatic paraplegics

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Abstract: OBJECTIVE: To investigate whether the combined approach of botulinum toxin type A (BtxA) and electrical stimulation was more effective than the toxin alone in the treatment of chronic upper limb spasticity after stroke. DESIGN: Randomized, placebo-controlled study with four treatment groups: 1000 units BtxA (Dysport) + electrical stimulation (A), 1000 units BtxA (B), placebo + electrical stimulation (C) and placebo (D). SETTING: A neurological rehabilitation clinic. SUBJECTS: Twenty-four stroke patients with chronic upper limb spasticity after stroke, six patients in each treatment group. INTERVENTIONS: Intramuscular injection of either toxin or placebo into six upper imb flexor muscles. In group A and C additional electrical stimulation of the injected muscles with surface electrodes, three times half an hour each day for three days. MAIN OUTCOME MEASURES: Muscle tone rated with the modified Ashworth score, limb position at rest and difficulties encountered during three upper limb motor tasks assessed before and 2, 6 and 12 weeks after injection. RESULTS: Most improvements were observed in patients of group A. Cleaning the palm ($p = 0.004$) differed across groups. Pairwise comparison for this target variable showed that group A differed from group B and D ($p < 0.01$), but not from C. Indicative across-group differences were obtained for elbow spasticity reduction ($p = 0.011$), and improvement of putting the arm through a sleeve ($p = 0.020$). CONCLUSIONS: The placebo-controlled trial favours the concept that electrical stimulation enhances the effectiveness of BtxA in the treatment of chronic upper limb flexor spasticity after stroke

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Abstract: Functional electrical stimulation can be used to provide hand opening in hemiplegics with spastic finger flexor muscles through stimulation of the extensor digitorum communis (EDC) muscle and the ulnar nerve. Stimulation of the finger extensor muscles in both hemiplegics and nonneurologically impaired individuals does not appear to cause significant reciprocal inhibition of finger flexor muscles.

Thus stimulation of the EDC and ulnar nerve may not decrease finger flexor spasticity in the hemiplegic subjects, yet functional hand opening can still be obtained through a direct mechanical effect of the extensor stimulation

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Abstract: The influence of suprathreshold electrical stimulation of the extensor and flexor carpi radialis muscles on biomechanical and functional movement parameters is compared with the effect of a standardized active repetitive training of hand and fingers. Twelve patients suffering from ischaemic lesions in the territory of the middle cerebral artery participated in the study, which was conducted using a multiple baseline design. Following a baseline phase that lasted between one and three weeks all patients received electrical muscle stimulation for 20 minutes twice daily. In a third phase the repetitive training of hand and fingers was conducted for 20 minutes twice daily. Both interventions were applied in addition to conventional occupational therapy and physiotherapy. With the exception of spasticity in hand and finger flexors, repetitive electrical muscle stimulation does not improve biomechanical or functional motor parameters of the centrally paretic hand and arm. The repetitive motor training, however, is appropriate to improve biomechanical and functional movement parameters significantly. Apart from a possible effect on the muscle cell itself, the electrical muscle stimulation is thought to represent a mainly sensory, i.e. proprioceptive, and cutaneous intervention, whereas the active motor training is characterized by a continuous sensorimotor coupling within motor centres of the brain. The underlying neurophysiological mechanisms as well as basic principles concerning the role of afferent input for motor learning and recovery are discussed

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Abstract: There is a growing body of evidence that the central nervous system (CNS), even in the adult animal, is capable of adaptation and reorganization not only as a result of partial damage to the CNS but also in response to stimulation. Environmental stimulation produces changes including expansion of visual cortex, increases in dendritic branching, glia and cholinesterase. Environmental stimulation also produces behavioural changes. Experimental electrical stimulation produces changes in synapse size, synaptic vesicle change, dendritic branching and changes in synaptic transmission. In man, repetitive electrical stimulation via epidural electrodes increases plasma levels of norepinephrine, epinephrine, and dopamine, and CSF levels of norepinephrine. Repetitive electrical stimulation in man dates back

to 1967 and has been used for the control of pain, to improve spasticity, bladder control, motor deficit and the autonomic hyperreflexia of spinal cord injury. In addition, improvement has been reported in epilepsy, cerebral palsy, torticollis and peripheral vascular diseases. The best controlled studies are in multiple sclerosis and peripheral vascular disease, and these results will be presented in more detail

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Abstract: In this study, the aim was to evaluate the influence on the cardiopulmonary system of muscular contractions of the paralyzed limbs in paraplegia, activated by FES during treatment, and the energy cost of standing and walking while using FES as an orthotic aid. Three traumatic spastic paraplegics were selected for the measurements. At the end of a 6 month training program heart rate and oxygen consumption of the patients were evaluated as follows: at rest; following 30 minutes of FES in the sitting position; following 15 minutes of standing; and during ambulation. Lactic acid level during maximal effort was evaluated as well. The results indicated a low energy cost of FES in the sitting position and during usage of FES as an orthotic device for standing, confirming the beneficial effect of FES for spastic paraplegics. However, effort invested during ambulation by means of FES was found exhaustive and FES is therefore advisable for young subjects mainly

Izzo K.L. and Aravabhumi S. (1989) Cerebrovascular accidents. Clin. Podiatr. Med. Surg. 6, 745-759.
Abstract: CVA comprises a large number of clinical entities, depending on the site of infarction in the brain. Accurate evaluation of deficits in the patient's sensory and/or motor systems and the patient's intellectual status are paramount in establishing realistic rehabilitation goals. With respect to the motor system, two types of voluntary movement may occur. These include synergistic or pattern movement and selective movement. Spasticity in the affected lower extremity may result in a variety of lower-extremity deformities and contractures. Those most commonly encountered include hip flexion and adduction contracture, inadequate knee flexion and knee flexion contracture, and ankle equinus, varus, and equinovarus. Correct evaluation of deformities may be aided by the use of poly-EMG analysis and evaluation after nerve block or motor point blocks. In hemiplegic gait dysfunction, the basic requirements for functional ambulation include (1) ability to maintain standing balance; (2) voluntary hip flexion; (3) leg stability; and (4) ability to follow instructions and adequate motivation. Often a hemiplegic patient can be trained to ambulate if an adequate extensor synergy pattern develops, since mass extension can provide stability of the leg for weight bearing. Medical rehabilitative management of the CVA patient includes early mobilization, restorative exercises (including neuromuscular facilitation techniques), measures to prevent or correct contractures, the use of AFOs, and occasionally functional electrical stimulation. Orthopedic management of deformities in CVA is indicated where conservative measures fail. Surgical procedures seek to alter the forces causing shortening of the muscles and tendons. Hence, the most commonly performed surgical procedures include (1) tendon lengthening or release; (2) soft-tissue release; and (3) tendon transfer. Surgery for hip contractures is not common; however, occasional release of hip flexors is indicated when hip flexion contracture impedes ambulation or prone lying. Inadequate knee flexion, caused by dysphasic quadriceps contraction, can be corrected by release of the vastus medialis and rectus femoris muscles. Distal

hamstring tendon release with or without knee joint capsule release is the surgical procedure of choice for severe knee flexion contractures. Surgical correction of an equinus deformity is by TAL, with or without neurectomy of tibial nerve branches to the gastrocsoleus muscles. Severe ankle varus may require a SPLATT procedure. Surgery for equinovarus includes the combined surgery for both equinus and varus (that is, TAL and SPLATT procedures). Toe curling is corrected by toe flexor releases.(ABSTRACT TRUNCATED AT 400 WORDS)

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Abstract: The importance of film documentation for objective and quantitative assessment of the results of epidural spinal electrical stimulation (ESES) was shown. Our experience is based on 25 patients with central motor disorders, predominantly of spinal origin. 17 were selected for internalization of a receiver system. By means of description and clinical registration of spasticity, reduced mobility, motor strength, dexterity, etc., or by means of electrophysiological tests, complex motor performance such as standing, sitting, dressing and undressing, eating and writing cannot be sufficiently evaluated. Short scenes of these activities when demonstrated by motion picture enable the therapist to compare better the condition of the patient before and with ESES, and thereby facilitate the selection of patients for internalization of receiver systems

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Abstract: We report on our advances in sensory feedback data processing and control system design for functional electrical stimulation (FES) assisted correction of foot drop. We have applied 2 methods of signal purification on the bin integrated electroneurogram (i.e., optimized low pass filtering and wavelet denoising) before training adaptive logic networks (ALN). ALN generated stimulation control pulses, which correspond to the swing phase of the impaired leg when dorsal flexion of the foot is necessary to provide safe ground clearance. However, the obtained control signal contained sporadic stimulation spikes in the stance phase, which can collapse the subject, and infrequent broken stimulation pulses in the swing phase, which can result in unpredictable consequences. In this study, we have introduced adaptive restriction rules (ARR), which are initially used as previously reported and then dynamically adapted during the use of the system. Our results suggest that ARR provide a safer and more reliable stimulation pattern than fixed restriction rules

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Abstract: Recent advances in science have aided research toward the restoration of biped gait in paraplegic patients by means of functional electrical stimulation (FES). In this paper it is shown how FES-restrengthened muscles of paraplegic patients have been used for simple FES-assisted standing. Those experiments subsequently led to biped gait-initializing experiments and to simple forms of biped gait synthesis. The purpose of this paper is to show the feasibility of using FES for standing and for restoring biped gait in many paraplegic patients--to present the past achievements, focus on problems, and highlight directions for future research. The results of gait obtained in three complete spinal cord injured patients (out of a series of 17) are shown, using four to six channels of FES. It is also shown how preserved reflex mechanisms of the transected spinal cord can be incorporated and employed for obtaining improved function while at the same time simplifying the FES hardware. Of the three patients reported on in detail here, two patients have managed to walk in parallel bars while the third patient has mastered independent unassisted walking over shorter distances with the aid of a roller walker. The biomechanical and control problems of this last patient's gait are presented in detail

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Abstract: Fifty hemiparetic subjects were selected from a population of 250 patients according to criteria forsuitable candidates for peroneal stimulation. The patients received from 10 to 120 hours of treatment during 2--5 weeks. The therapeutic results obtained were classified into four groups, ranging from none to excellent improvement of voluntary movement and reduction of spasticity. The clinical results were correlated to different variables where time from lesion, spasticity, and extent of treatment appeared to be the most important ones. The percentage of excellent results decreased with increasing time from lesion and spasticity, and increased with increasing treatment. Orthotic validity (i.e. the beneficial effect of the orthosis) was observed in 76% of the selected cases and in most of them it was very significant. Preliminary tests performed on 9 subjects showed that in cases with orthotic validity the peroneal brace slightly reduces the oxygen consumption of patients and improves their motivation. This work gives a more quantitative perspective of the validity of functional peroneal stimulation and a better indication of criteria for patient selection. The overall validity of an electronic peroneal brace appears to apply to

15% of the total ambulatory hemiparetic population and its therapeutic value is relevant in two- thirds of such cases if sufficient treatment is provided. Application of functional electrical stimulation to non-ambulatory subjects in the acute phase may however lead to a higher percentage of cases of therapeutic validity

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Abstract: Transcutaneous electrical stimulation was applied to the penis in 22 patients complaining of frequency, urgency and/or urge incontinence. Detrusor activity was suppressed with this stimulation, causing decreased bladder spasticity and/or increased cystometric capacity in 10 of 22 patients. Clinical success was noted in four patients with a portable stimulator

Nashold B.S., Jr., Grimes J., Friedman H., Semans J., and Avery R. (1977) Electrical stimulation of the conus medullaris in the paraplegic. A 5- year review. Appl. Neurophysiol. 40, 192-207.
Abstract: In 1970 we carried out the first electrode implantation of the conus medullaris of a 17-year-old male paraplegic to control the emptying of his paralyzed bladder. Our patient has used electromicturition for 6 years to successfully empty his bladder and prevent urinary infection. To date, a total of 11 paraplegic patients have been implanted (6 males, 5 females). The cause of the paraplegia was the result of trauma, and the implants were performed from 16 days to 15 years postinjury. All the patients had experienced numerous urinary infections and required constant catheter drainage, and it was the opinion of our urologic associate that current methods of control of the bladder problem were of no avail. The bladder was considered to be atonic in 7 patients and spastic in 4. The results indicate that after a follow-up of 1--6 years, 8 patients have complete control of voiding by electrical stimulation (4 female, 4 male). 2 of the males required partial sphincterotomy to improve emptying, but none of the females experienced sphincter interference. One male quadriparetic patient died 7 months postimplantation of pneumonia and hepatitis. There have been no infections related to the implantable device; however, 1 female broke the connecting wires to the spinal cord electrode during a paraplegic basketball game. In addition to the induced electrical contraction of the bladder, we have observed increased autonomic activity below the level of the spinal cord transection, improved defecation, reduction of spasticity in the paralyzed legs, penile erection in males, and reduction of decalcification of the long bones. This group of patients represents the longest use of an implantable electronic device to control bladder function

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O'Brien C.F. (1997) Injection techniques for botulinum toxin using electromyography and electrical stimulation. Muscle Nerve Suppl 6, S176-S180.
Abstract: Increasing data supports the use of botulinum toxin injection as a therapeutic intervention in the management of spasticity. The avid binding of botulinum toxin (BTX) to presynaptic neuron terminals and the diffusion characteristics of the medication allow relative ease of administration. For many clinical applications, efficacy may be improved, and adverse effects reduced, by more precise targeting of the muscles to be injected. Electromyographic guidance (EMG) is commonly used to confirm appropriate localization of the injection needle in specific muscles immediately before injection. Electrical stimulation (ES) may be more useful in patients who are unresponsive or sedated. Equipment options and technical aspects of EMG and ES are discussed, including some adjunctive imaging methods for injecting difficult-to- localize muscles

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Pease W.S. (1998) Therapeutic electrical stimulation for spasticity: quantitative gait analysis. Am. J. Phys. Med. Rehabil. 77, 351-355.
Abstract: Improvement in motor function following electrical stimulation is related to strengthening of the stimulated spastic muscle and inhibition of the antagonist. A 26-year-old man with familial spastic paraparesis presented with gait dysfunction and bilateral lower limb spastic muscle tone. Clinically, muscle strength and sensation were normal. He was considered appropriate for a trial of therapeutic electrical stimulation following failed trials of physical therapy and baclofen. No other treatment was used concurrent with the electrical stimulation. Before treatment, quantitative gait analysis revealed 63% of normal velocity and a crouched gait pattern, associated with excessive electromyographic activity in the hamstrings and gastrocnemius muscles. Based on these findings, bilateral stimulation of the quadriceps and anterior compartment musculature was performed two to three times per week for three months. Repeat gait analysis was conducted three weeks after the cessation of stimulation treatment. A 27% increase in velocity was noted associated with an increase in both cadence and right step length. Right hip and bilateral knee stance motion returned to normal (rather than "crouched"). No change in the timing of dynamic electromyographic activity was seen. These findings suggest a role for the use of electrical stimulation for rehabilitation of spasticity. The specific mechanism of this improvement remains uncertain

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Pinter M.M., Gerstenbrand F., and Dimitrijevic M.R. (2000) Epidural electrical stimulation of posterior structures of the human lumbosacral cord: 3. Control Of spasticity. Spinal Cord. 38, 524-531.
Abstract: OBJECTIVES: The purpose of this study was to evaluate the effect of spinal cord stimulation (SCS) on severe spasticity of the lower limbs in patients with traumatic spinal cord injury (SCI) under close scrutiny of the site and parameters of stimulation. MATERIALS AND METHODS: Eight SCI patients (four women, four men) were included in the study. Levels of spasticity before and during stimulation were compared according to a clinical rating scale and by surface electrode polyelectromyography (pEMG) during passive flexion and extension of the knee, supplemented by a pendulum test with the stimulating device switched either on or off over an appropriate period. RESULTS: Both the clinical and the experimental parameters clearly demonstrated that SCS, when correctly handled, is a highly effective approach to controlling spasticity in spinal cord injury subjects. The success of this type of treatment hinges on four factors: (1) the epidural electrode must be located over the upper lumbar cord segment (L1, L2, L3); (2) the train frequency of stimulation must be in the range of 50 - 100 Hz, the amplitude within 2 - 7 V and the stimulus width of 210 micross; (3) the stimulus parameters must be optimized by clinically assessing the effect of arbitrary combinations of the four contacts of the quadripolar electrode; and (4) amplitudes of stimulation must be adjusted to different body positions. CONCLUSIONS: Severe muscle hypertonia affecting the lower extremities of patients with chronic spinal cord injuries can be effectively suppressed via stimulation of the upper lumbar cord segment

Popovic D., Stein R.B., Oguztoreli N., Lebiedowska M., and Jonic S. (1999) Optimal control of walking with functional electrical stimulation: a computer simulation study. IEEE Trans. Rehabil. Eng 7, 69-79.
Abstract: Bipedal locomotion was simulated to generate a pattern of activating muscles for walking using electrical stimulation in persons with spinal cord injury (SCI) or stroke. The simulation presented in this study starts from a model of the body determined with user-specific parameters, individualized with respect to the lengths, masses, inertia, muscle and joint properties. The trajectory used for simulation was recorded from an able-bodied subject while walking with ankle-foot orthoses. A discrete mathematical model and dynamic programming were used to determine the optimal control. A cost function was selected as the sum of the squares of the tracking errors from the desired trajectories, and the weighted sum of the squares of agonist and antagonist activations of the muscle groups acting around the hip and knee joints. The aim of the simulation was to study plausible trajectories

keeping in mind the limitations imposed by the spinal cord injury or stroke (e.g., spasticity, decreased range of movements in some joints, limited strength of paralyzed, externally activated muscles). If the muscles were capable of generating the movements required and the trajectory was achieved, then the simulation provided two kinds of information: 1) timing of the onset and offset of muscle activations with respect to the various gait events and 2) patterns of activation with respect to the maximum activation. These results are important for synthesizing a rule-based controller

Potisk K.P., Gregoric M., and Vodovnik L. (1995) Effects of transcutaneous electrical nerve stimulation (TENS) on spasticity in patients with hemiplegia. Scand. J. Rehabil. Med. 27, 169-174.
Abstract: The effect of afferent cutaneous electrical stimulation on the spasticity of leg muscles was studied in 20 patients with chronic hemiplegia after stroke. Stimulation electrodes were placed over the sural nerve of the affected limb. The standard method of cutaneous stimulation, TENS with impulse frequency of 100 Hz, was applied. The tonus of the leg muscles was measured by means of an electrohydraulic measuring brace. The EMG stretch reflex activity of the tibialis anterior and triceps surae muscles was detected by surface electrodes and recorded simultaneously with the measured biomechanical parameters. In 18 out of 20 patients, a mild but statistically significant decrease in resistive torques at all frequencies of passive ankle movements was recorded following 20 min of TENS application. The decrease in resistive torque was often (but not always) accompanied by a decrease in reflex EMG activity. This effect of TENS persisted up to 45 min after the end of TENS. The results of the study support the hypothesis that TENS applied to the sural nerve may induce short-term post- stimulation inhibitory effects on the abnormally enhanced stretch reflex activity in spasticity of cerebral origin

Price C.I. and Pandyan A.D. (2000) Electrical stimulation for preventing and treating post-stroke shoulder pain (Cochrane Review). Cochrane. Database. Syst. Rev. CD001698.
Abstract: BACKGROUND: Shoulder pain after stroke is common and disabling. The optimal management is uncertain, but electrical stimulation (ES) is often used to treat and prevent pain. OBJECTIVES: The objective of this review was to determine the efficacy of any form of surface ES in the prevention and / or treatment of pain around the shoulder at any time after stroke. SEARCH STRATEGY: We searched the Cochrane Stroke Review Group trials register and undertook further searches of MEDLINE, EMBASE and CINAHL. Contact was established with equipment manufacturers and centres that have published on the topic of ES. SELECTION CRITERIA: We considered all randomised trials that assessed any surface ES technique (functional electrical stimulation (FES), transcutaneous electrical nerve stimulation (TENS) or other), applied at any time since stroke for the purpose of prevention or treatment of shoulder pain. DATA COLLECTION AND ANALYSIS: Two reviewers independently selected trials for inclusion, assessed trial quality and extracted the data. MAIN RESULTS: Four trials (a total of 170 subjects) fitted the inclusion criteria. Study design and ES technique varied considerably, often precluding the combination of studies. Population numbers were small. There was no significant change in pain incidence (Odds Ratio (OR) 0.64; 95% CI 0.19 to 2.14) or change in pain intensity (Standardised Mean Difference (SMD) 0.13; 95% CI -1.0 to 1.25) after ES treatment compared to control. There was a significant treatment

effect in favour of ES for improvement in pain-free range of passive humeral lateral rotation (Weighted Mean Difference (WMD) 9.17; 95% CI 1.43 to 16.91). In these studies ES reduced the severity of glenohumeral subluxation (SMD -1.13; 95% CI -1.66 to -0.60), but there was no significant effect on upper limb motor recovery (SMD 0.24; 95% CI -0.14 to 0.62) or upper limb spasticity (WMD 0.05; 95% CI -0.28 to 0.37). There did not appear to be any negative effects of electrical stimulation at the shoulder. REVIEWER'S CONCLUSIONS: The evidence from randomised controlled trials so far does not confirm or refute that ES around the shoulder after stroke influences reports of pain, but there do appear to be benefits for passive humeral lateral rotation. A possible mechanism is through the reduction of glenohumeral subluxation. Further studies are required

Price C.I. and Pandyan A.D. (2001) Electrical stimulation for preventing and treating post-stroke shoulder pain: a systematic Cochrane review. Clin. Rehabil. 15, 5-19. Abstract: BACKGROUND: Shoulder pain after stroke is common and disabling. The optimal management is uncertain, but electrical stimulation (ES) is often used to treat and prevent pain. OBJECTIVES: The objective of this review was to determine the efficacy of any form of surface ES in the prevention and/or treatment of pain around the shoulder at any time after stroke. SEARCH STRATEGY: We searched the Cochrane Stroke Review Group trials register and undertook further searches of Medline, Embase and CINAHL. Contact was established with equipment manufacturers and centres that have published on the topic of ES. SELECTION CRITERIA: We considered all randomized trials that assessed any surface ES technique (functional electrical stimulation (FES), transcutaneous electrical nerve stimulation (TENS) or other), applied at any time since stroke for the purpose of prevention or treatment of shoulder pain. DATA COLLECTION AND ANALYSIS: Two reviewers independently selected trials for inclusion, assessed trial quality and extracted the data. MAIN RESULTS: Four trials (a total of 170 subjects) fitted the inclusion criteria. Study design and ES technique varied considerably, often precluding the combination of studies. Population numbers were small. There was no significant change in pain incidence (odds ratio (OR) 0.64; 95% CI 0.19-2.14) or change in pain intensity (standardized mean difference (SMD) 0.13; 95% CI -1.0-1.25) after ES treatment compared with control. There was a significant treatment effect in favour of ES for improvement in pain-free range of passive humeral lateral rotation (weighted mean difference (WMD) 9.17; 95% CI 1.43-16.91). In these studies ES reduced the severity of glenohumeral subluxation (SMD -1.13; 95% CI -1.66 to -0.60), but there was no significant effect on upper limb motor recovery (SMD 0.24; 95% CI -0.14-0.62) or upper limb spasticity (WMD 0.05; 95% CI -0.28-0.37). There did not appear to be any negative effects of electrical stimulation at the shoulder.REVIEWERS' CONCLUSIONS: The evidence from randomized controlled trials so far does not confirm or refute that ES around the shoulder after stroke influences reports of pain, but there do appear to be benefits for passive humeral lateral rotation. A possible mechanism is through the reduction of glenohumeral subluxation. Further studies are required

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Remy-Neris O., Barbeau H., Daniel O., Boiteau F., and Bussel B. (1999) Effects of intrathecal clonidine injection on spinal reflexes and human locomotion in incomplete paraplegic subjects. Exp. Brain Res. 129, 433-440.
Abstract: We studied the effect of the intrathecal (i.t.) injection of clonidine (30, 60 and 90 microg) on the polysynaptic spinal reflexes (PSR) elicited by electrical stimulation of flexor reflex afferents (FRA), monosynaptic reflex and gait of 11 subjects with spinal cord injuries. The effect of clonidine administration on gait velocity, stride amplitude and duration was measured in eight subjects who were able to walk. Five subjects were able to walk after intrathecal injection of clonidine and three were not able to stand up. Three subjects improved their gait velocity after clonidine administration; one (S6) increased his stride amplitude; the two others decreased their cycle durations. The tibialis anterior seemed to be more regularly activated during gait. Spasticity was reduced dramatically ($P<0.0001$) after i.t. clonidine injection, but there was no statistically significant difference in the soleus H reflex (no effect on Hmax/Mmax). Clonidine administration decreased the amplitude of the early PSR (90-120 ms, N=4) and the threshold and maximal integrated EMG corresponding to the late response (140-450 ms, N=7). This effect was dose dependent (30, 60 and 90 microg). Placebo injection (N=4) caused no change. The changes in spinal reflexes, with a large reduction in spasticity, no change in motoneurone excitability and a large decrease in PSR, suggest that clonidine acts at a premotoneuronal level, possibly by presynaptic inhibition of group II fibres. The increase in gait velocity in three subjects could have been due to reduced spasticity or activation of spinal circuitry

Reswick J.B. and Simoes N. (1975) Application of engineering principles in management of spinal cord injured patients. Clin. Orthop. 124-129.
Abstract: Engineering services currently being used for spine stabilization, respiratory assist, and pressure sore prevention are discussed as well as devices under development for bowel and bladder control, reduction of contractural deformities and spasticity, and electrical stimulation of paralyzed muscles. Concepts and devices for improved function are divided into categories of: orthotic devices; environmental control systems; mobility systems; page-turning devices. A wide range of engineering devices are available but strict attention must be given to medical rationale for their use

Robinson C.J., Kett N.A., and Bolam J.M. (1988) Spasticity in spinal cord injured patients: 2. Initial measures and long-term effects of surface electrical stimulation. Arch. Phys. Med. Rehabil. 69, 862-868.
Abstract: Electrical stimulation of paralyzed muscles has been shown to affect their spasticity, especially in patients with hemiplegia. But little has been reported on the long-term effects of such stimulation on individuals with spinal cord injury. This paper documents initial quadriceps spasticity in 31 spinal cord injured subjects, and the effect of four to eight weeks of reconditioning using electrical stimulation. Spasticity was quantified through the use of a normalized relaxation index (R2n) obtained from a pendulum drop test. The reconditioning protocol consisted of twice daily 20-minute exercise sessions at least four hours apart, six days per week. Spasticity and stimulated quadriceps torque were measured during one to three evaluations performed at least one day apart at the beginning of the program, and at four and

eight weeks. There was no significant difference in average initial measures of spasticity between left and right legs and no effect of time since injury on average R2n values. Significant differences were seen for right leg average baseline R2n values when grouped by lesion level or completeness. Quadriplegic individuals were more spastic than paraplegic individuals, and subjects with incomplete lesions were more spastic than those with complete lesions. These findings are interrelated since most of the quadriplegic subjects (14 of 16) had incomplete lesions. Most participants had increased spasticity after four weeks of reconditioning but not after eight weeks. However, only eight subjects completed eight weeks of reconditioning. Subjects who had the greatest increases in spasticity also had the greatest gains in stimulated torque, both after four and eight weeks.(ABSTRACT TRUNCATED AT 250 WORDS)

Robinson C.J., Kett N.A., and Bolam J.M. (1988) Spasticity in spinal cord injured patients: 1. Short-term effects of surface electrical stimulation. Arch. Phys. Med. Rehabil. 69, 598-604.
Abstract: Twelve spinal cord injured subjects participated in a study of the short-term effects on leg spasticity of electrical stimulation of the quadriceps. Spasticity was quantified through the use of a normalized relaxation index (R2n) obtained from the pendulum drop test both before and after measurement of isometric quadriceps torque in response to 20 minutes of cyclic electrical stimulation. Two or three baseline evaluations were made on each subject, tests being at least one day apart. By comparing the first prestimulus baseline assessment of spasticity with that obtained poststimulus, we obtained a measure of changes in spasticity brought about by fatiguing exercise. We found that spasticity significantly (p less than or equal to 0.005) decreased after stimulation. To investigate whether this change was due to electrical stimulation or was a function of the performance of the drop test itself (ie, passive range of motion of the knees), drop-to-drop variability during the pendulum drop test both before and after stimulation was assessed. A comparison was made of the R2n value of the last drop before stimulation to that of the first drop afterward, to assess the direct effect of stimulation on spasticity. Spasticity decreased significantly (p less than or equal to 0.05) during the leg ranging inherent in the drop test itself, particularly for subjects with shorter times postinjury. Spasticity also decreased significantly as a direct result of electrical stimulation. This latter change could be accounted for by an interaction of peak quadriceps torque and the initial measure of spasticity before stimulation.(ABSTRACT TRUNCATED AT 250 WORDS)

Roper B.A. (1987) The orthopedic management of the stroke patient. Clin. Orthop. 78-86.
Abstract: The basic problem following a cerebrovascular accident is that the normal inhibitory regulating mechanism, the cerebral motor cortex, is damaged to a variable extent. This releases primitive peripheral reflex activities resulting in aberrant function of limbs and restricted motion in joints. The sensory cortex can equally be damaged and careful assessment of sensory appreciation in the stroke patient has to be made. The initial treatment of patients after a stroke consists of a variety of physiotherapy techniques, the rationale of which is to reduce the power of dominant aberrant reflex activities and build the strength in the antagonistic group of muscles. The potential for the efficacy of physiotherapy is somewhat restricted, but there is a place for appropriate bracing. A certain number of patients exist, however, for whom physiotherapy cannot achieve the desired results and for whom bracing is either

ineffective or unacceptable. The only alternative for these patients is functional electrical stimulation or reducing the activity in the deforming muscles. This can either be done by direct inactivation of the motor nerve or by actually lengthening the muscle tendon unit to reduce the power of the muscle group. An alternative is to transfer tendons

Rushton D.N., Barr F.M., Donaldson N., Harper V.J., Perkins T.A., Taylor P.N., and Tromans A.M. (1998) Selecting candidates for a lower limb stimulator implant programme: a patient-centred method. Spinal Cord. 36, 303-309.
Abstract: OBJECTIVE: To develop an effective selection procedure for lower limb functional neurostimulation (LLFNS) for standing in paraplegia. DESIGN: The selection procedure and exclusion criteria were based on the previous experience for two clinical centres with experience of LLFNS. SETTING: Two Regional Spinal Injuries units in southern England. SUBJECTS: 254 fully rehabilitated paraplegics living in the community. INTERVENTION: Patients were invited to participate in the programme, and if suitable to subject themselves to a rigorous staged selection procedure from which they could withdraw at any time. OUTCOME MEASURE: Functionally successful home standing using closed-loop surface electrical stimulation. RESULTS: 57/254 patients were suitable on paper and were accessible. 19 of these (CI = 10-28) were interested in the project and attended one of the spinal centres for details. Twelve (CI = 5-19) of these fulfilled the selection criteria and started on the training programme; and 10 of them completed the muscle training programme successfully. Seven patients (CI = 2-12) achieved closed-loop standing in the laboratory and four patients (CI = 1-8) did so at home

Scheker L.R., Chesher S.P., and Ramirez S. (1999) Neuromuscular electrical stimulation and dynamic bracing as a treatment for upper-extremity spasticity in children with cerebral palsy. J. Hand Surg. [Br.] 24, 226-232.
Abstract: We have investigated a therapeutic regimen using neuromuscular electrical stimulation (NMES) and dynamic bracing to assess their effectiveness in reducing upper-extremity spasticity in children with cerebral palsy. Nineteen patients between 4 and 21 years of age with documented diagnoses of spastic cerebral palsy were treated. The patients included in the study followed a regimen of two 30-minute sessions of NMES of the antagonist extensors combined with dynamic orthotic traction during the day. A static brace was used at night. Spasticity of the wrist and fingers was assessed periodically using the Zancolli classification. Treatment ranged from 3 to 43 months. After treatment with electrical stimulation and dynamic bracing, all the patients moved up 1 to 3 levels in the Zancolli classification and showed a marked improvement in upper-extremity function. These results show that combining NMES and dynamic orthotic traction dramatically decreases spasticity of the upper extremity in young patients with cerebral palsy

Schlecht M., Snoek G., Kleissen R, Zilvold G. (1987) Quantitative Evaluation of the Effect of Spinal Cord Stimulation on Motor Function. *Adv External Control of Human Extremities* IX, 405-413.

Seib T.P., Price R., Reyes M.R., and Lehmann J.F. (1994) The quantitative measurement of spasticity: effect of cutaneous electrical stimulation. Arch. Phys. Med. Rehabil. 75, 746-750.
Abstract: The goal of this research was to determine if cutaneous electrotherapy would temporarily reduce muscle spasticity. Five traumatically brain injured (TBI) and

five spinal cord injured (SCI) subjects, all with clinically evident spasticity, received surface electrical stimulation over the tibialis anterior muscle. Using the Spasticity Measurement System, stiffness around the ankle was measured before, immediately after, and 24 hours after treatment. With stimulation, ipsilateral ankle viscoelastic stiffness immediately decreased in 9 of 10 subjects and remained significantly depressed for up to 24 hours. Contralateral ankle spasticity did not significantly change. Using the same subjects under sham conditions, no significant decrements in spasticity occurred. In a subjective survey, only SCI participants reported functionally evident spasticity reductions. Also within this subgroup, efficacy of treatment was directly proportional to the severity of pre- stimulation clonus. We conclude that (1) cutaneous electrotherapy transiently decreases both TBI and SCI related spasticity and (2) pre- stimulation clonus may function as a clinical indicator of SCI patients most likely to benefit from this process

Shatin D., Mullett K. (1989) A Multi-Center Study of the Treatment of Spasticity with Spinal Cord Stimulation. *Phys Med and Rehabil: State of the Art Reviews* 3, 151-160.

Siegfried J. (1980) Treatment of spasticity by dorsal cord stimulation. Int. Rehabil. Med. 2, 31-34.
Abstract: Two types of operations can be proposed today in the neurosurgical treatment of spasticity; the destruction of a brain target, a medullary pathway or a nerve root, and electrical stimulation of nervous structures. Striking improvements in voluntary motor control and sensory appreciation were first reported by Cook and Weinstein (1) in 1973, after implantation of a dorsal cord stimulator for intractable back pain in a case of muiltiple scleroris. The favourable effect on spasticity was confirmed later by other groups. Our own experience, with 26 cases tested for a few days with floating electrodes and 11 cases operated on and followed up for more than 3 years, shows that the best results are obtained in cases of medullary spasticity, without complete section of the cord, occurring mainly in multiple sclerosis. Cerebral spasticity did not respond as well. The objective data, measurement of stretch and H-reflexes, support the clinical results. The physiological mechanisms of dorsal cord stimulation on spasticity have not yet been elucidated

Siegfried J., Lazorthes Y., and Broggi G. (1981) Electrical spinal cord stimulation for spastic movement disorders. Appl. Neurophysiol. 44, 77-92.
Abstract: Clinical results of electrical stimulation of the spinal cord at three different clinics are reported for 53 patients suffering from different spastic movement disorders out of a series of 164 cases tested transitorily. Two-thirds of the cases were multiple sclerosis patients. The difficulty of objective assessment is emphasized. Motor function was principally evaluated and surprisingly showed a marked improvement 1-5 years after the implantation of an electrical device. Other criteria are analyzed and compared with literature. Dorsal cord stimulation seems to be a valuable method for improving the quality of life in a limited percentage of cases of neurological motor disorders

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Solomonow M., Aguilar E., Reisin E., Baratta R.V., Best R., Coetzee T., and D'Ambrosia R. (1997) Reciprocating gait orthosis powered with electrical muscle stimulation (RGO II). Part I: Performance evaluation of 70 paraplegic patients. Orthopedics 20, 315-324.
Abstract: Seventy paraplegics were fitted with an improved Reciprocating Gait Orthosis powered with or without (low-level injury) electrical stimulation of the thigh muscles (RGO II) as a secondary rehabilitation phase after the acute period. The patients comprised a broad cross- section of the paraplegic population applying for medical services and varied in age from 16 to 55 years, time since injury ranging from less than 1 to 15 years, injury levels ranging from C-6/7 to T-11/12, and varying levels of spasticity, contractures, scoliosis and other related medical and physiologic problems. The success/failure ratio was dependent on the injury level, which was 1:1 for paraplegics with injury level at C-6/7; 1.67:1 for those with injury of T-1/3; and about 4:1 for paraplegics with injury level from T-3 to T-12. Lack of motivation and medical problems unrelated to the RGO II treatment were the primary reasons for failure. The duration of treatment (outpatient service three times per week) ranged from 2 to 48 weeks (mean: 16). Forty-one patients who completed the RGO II rehabilitation and were sent home with the orthosis for independent use (for at least 6 months and up to 3 years) were surveyed by a staff member for analysis of the meaning and impact of the RGO II on the patient's life and health, and potential problems. It was shown that 80.5% of the 41 patients were regular users and 19.5% were non-users. Thirty-eight of the 41 patients declined an offer to return the RGO II equipment for a full refund, while three patients were willing to return the orthosis. It was concluded that the RGO II is viable orthosis for restoring standing and limited walking in paraplegics while providing sufficient function, safety, and reliability. The most appropriate patients for the use of such an orthosis consist primarily of those with T-3 to T-12 injury level and good motivation, although highly selected patients with higher injury levels also can benefit from its use. Regular use of the RGO II, even for exercise only, had a general positive impact on the patients' health and outlook

Stefanovska A., Gros N., Vodovnik L., Rebersek S., and Acimovic-Janezic R. (1988) Chronic electrical stimulation for the modification of spasticity in hemiplegic patients. Scand. J. Rehabil. Med. Suppl 17, 115-121.
Abstract: The effects of long-term electrical stimulation on reflex hyperactivity and voluntary muscle control were studied. Eight hemiplegic patients with implanted peroneal stimulator were included. After six months of functional electrical stimulation (FES) there was a decrease of tonic activity in both tibialis anterior and triceps surae muscles. The phasic stretch reflex activity in the stimulated tibialis anterior muscle increased. The resulting resistance during passive movements decreased due to diminution of tonic activity. The absence of tonic activity also resulted in improvement of voluntary control, particularly in the tibialis anterior muscle

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Abstract: A randomized controlled trial was carried out to determine the effectiveness of therapeutic electrical stimulation (TES) in improving the function of children with spastic cerebral palsy (CP), who had undergone selective posterior lumbosacral rhizotomy more than a year previously. Children were randomly assigned to groups to receive TES for 1 year, or to have no TES. The primary outcome was the change in the Gross Motor Function Measure (GMFM), a quantitative and validated measure for use in children with spastic CP. There was a statistically significant and clinically important improvement in outcome for the treated children, with the mean change in the GMFM score at one year being 5.5% compared with 1.9% in the untreated group (P = 0.001). TES was simple to use, had no significant complications, and was well accepted by the children and their caregivers, as indicated by an average compliance of 93% for the application of TES on a nightly basis over the course of the study. It was concluded that TES may be beneficial in children with spastic CP who have undergone a selective posterior rhizotomy procedure more than 1 year previously

Stenehjem J., Swenson J.R., Grange T.S. (1987) Spasticity Evaluation by Ambulatory EMG. *Adv External Control of Human Extremities* IX, 385-392.

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Toft E. (1995) Mechanical and electromyographic stretch responses in spastic and healthy subjects. Acta Neurol. Scand. Suppl 163, 1-24.
Abstract: The reflex mediated mechanical response was studied in the ankle flexors and ankle extensors of healthy and spastic subjects at maintained contractions from low to high concentration levels. This was done by a technique where muscle stretches could be applied during contractions with stretch reflex responses present or during contractions where the stretch reflex was absent. Stretch responses without stretch reflexes were obtained during contractions elicited by electrical stimulation. The validity of this method is discussed in details and it is concluded that the stretch responses during electrical stimulation can give a correct estimate of the non-reflex muscle response. The method is difficult to carry out in many human subjects and a number of precautions have to be taken. In healthy subjects a large reflex mediated mechanical response was found in the ankle flexors and ankle extensors, with the largest response at low and intermediate contraction levels. Surprisingly the reflex mediated mechanical response was found to be of equal size in the ankle extensors of spastic patients and control subjects at all contraction levels. In the ankle flexors no reflex mediated mechanical response was present in the patients contrary to the findings in the control subjects. A method was developed to predict the reflex mediated mechanical response from the reflex mediated EMG

response. The method was successfully applied in the ankle flexors. In the ankle extensors the measured reflex mediated mechanical response was a factor of 2.5 lower than the EMG predicted mechanical reflex response. It was concluded that the method cannot be applied in situations where a large synchronized EMG response occurs--as it does in the ankle extensors. An increased EMG response was found in the ankle extensors in spastic patients, but this was not followed by an increased mechanical reflex response. This emphasizes that conclusions drawn from EMG results should be done with caution. Stretch reflexes are increased in spastic patients during clinical examination. This is in contrast to the findings under our experimental conditions, where the reflex mediated response during maintained contraction was decreased in the ankle flexors and unchanged in the ankle extensors of spastic patients. Others have found that the H-reflex is modulated in healthy subjects in relation to different motor tasks. It was proposed that healthy subjects set the reflex in a facilitated state in relation to ongoing contraction under our experimental conditions and perhaps in a more inhibited state in the clinical test situation.(ABSTRACT TRUNCATED AT 400 WORDS)

Van der Meche F.G.A., Gijn J.V. (1986) Hypotonia: An Erroneous Clinical Concept? *Brain* 109, 1169-1178.

van Griethuysen C.M., Paul J.P., Andrews B.J., and Nicol A.C. (1982) Biomechanics of functional electrical stimulation. Prosthet. Orthot. Int. 6, 152-156.
Abstract: Patients with hemiplegia frequently have difficulty in walking due to lack of eversion and dorsiflexion capability of the foot. One method of treating these patients utilizes functional electrical stimulation (FES). The effect of FES on locomotion, co-ordination, proprioception and balance sense was assessed using instrumented gait analysis and a postural sway test. In general patients treated with FES showed either a marked improvement or very little change. Any improvement was reflected in postural sway and ankle control during locomotion. Changes in hip and knee control were insignificant

Vodovnik L., Bowman B.R., and Winchester P. (1984) Effect of electrical stimulation on spasticity in hemiparetic patients. Int. Rehabil. Med. 6, 153-156.
Abstract: Cyclical electrical stimulation has been applied to 10 hemiparetic patients with clinical signs of knee joint spasticity. The programme included 30 minutes of stimulation to the hamstrings followed by another 30 minutes of stimulation to the hamstrings and quadriceps. None of the patients experienced increased spasticity. The reduction in spasticity ranged from none to substantial with some other beneficial side-effects. No conclusions could be drawn as to whether hamstring stimulation is preferred to combined stimulation or to quadriceps stimulation alone. It is suggested that small portable stimulators be introduced for chronic use in spastic patients after an optimum stimulation regimen is individually established for each patient

Vodovnik L., Bowman B.R., and Hufford P. (1984) Effects of electrical stimulation on spinal spasticity. Scand. J. Rehabil. Med. 16, 29-34.
Abstract: Seven spinal cord injured (SCI) patients with clinical signs of knee- joint spasticity were tested with the Wartenberg pendulum test and an electrogoniometer. All patients were subjected to four channel rhythmical electrical stimulation of the knee muscles for three consecutive days. In five patients some improvement of spasticity was achieved. No increase of spasticity was observed in any patient.

Combining results from two separate but similar studies it is contended that about one-half of randomly selected SCI patients with knee joint spasticity might benefit by electrical stimulation

Vodovnik L., Stefanovska A., Bajd T. (1987) Effects of stimulation parameters on modification of spinal spasticity. *Med & Biol Eng & Comput* 25, 439-442.

Vodovnik L., Rebersek S., Stefanovska A., Zidar J., Acimovic R., and Gros N. (1988) Electrical stimulation for control of paralysis and therapy of abnormal movements. Scand. J. Rehabil. Med. Suppl 17, 91-97.
Abstract: After a short review of the functional aspects of electrical stimulation in rehabilitating paralysed patients, the article describes its effects on spasticity. Three different studies are briefly described. In the first one paraplegic patients' knee extensors and flexors were stimulated with four channel stimulator. In the second one two channel stimulation was applied to the ankle joint flexors and extensors in hemiplegic patients, while in the third, the effects of spinal cord stimulation were studied in multiple sclerosis patients. Although the parameters and sites of stimulation were different in each study, the effects were similar. In approximately 50% of paraplegic and hemiplegic patients stimulation caused decrease of reflex activity which lasted more than half an hour. In M.S. patients measurements were performed only in intervals of day and therefore short term effects were not documented. Two days after interruption of continuous spinal cord stimulation the reflex activity significantly increased in the majority of patients. In addition to this increase the volitional force decreased considerably

Vuco J., Anastasijevic R. (1988) Fusimotor Activity: Its Possible Significance in Muscle Hypertonia. *Scand J Rehab Med* Suppl 17, 133-138.

Walker J.B. (1982) Modulation of spasticity: prolonged suppression of a spinal reflex by electrical stimulation. Science 216, 203-204.
Abstract: Electrical subcutaneous nerve stimulation of radial, median, and saphenous nerves has been shown to produce prolonged analgesia. In a double blind study, such stimulation also suppressed clonus for 3 hours after stimulation ceased in subjects with spasticity. Since the effect is contralateral, each subject was his own control. Because stimulation of the nerve in the wrist suppressed ankle clonus, the mechanism mediating the effect must be centrifugal inhibition. These results suggest that subcutaneous nerve stimulation may also be a tool in the management of spasticity

Walker J.B. (1983) Electrical stimulation enhanced recovery of function: how are peptides involved? Lancet 2, 912.

Waters R.L. (1984) The enigma of "carry-over". Int. Rehabil. Med. 6, 9-12.
Abstract: It is well known that after the cessation of treatment by functional electrical stimulation (FES) there is a continuation of the improvement of the muscle function "carry-over". If this could be harnessed and understood then this might lead to permanent improvement. An examination of evidence from FES, spasticity research and biofeedback might well produce the answers

Weingarden H.P., Kizony R., Nathan R., Ohry A., and Levy H. (1997) Upper limb functional electrical stimulation for walker ambulation in hemiplegia: a case report.

Am. J. Phys. Med. Rehabil. 76, 63-67.
Abstract: Electrical stimulation has been sporadically used in the treatment of hemiplegia. Reported benefits include decreasing spasticity, providing a supplementary means for range of motion exercises, increasing strength, and improving local blood flow in a paretic or paralyzed limb. Some studies have also shown functional gains in the hemiplegic upper limb following treatment with electrical stimulation. Nevertheless, there have been very few reports of the use of neuromuscular stimulation to achieve new hemiplegic upper limb activity not possible without the electrical stimulation. This is a case report of a head injury patient who was able to begin ambulation with a walker, without physical assistance, for the first time in the 16 yr since his injury. A new electrical stimulation device (Handmaster) initially used therapeutically, and then functionally, provided a reliable, strong grasp and release and was instrumental in achieving the new level of function. The device proved to be easy to use in the home, giving the patient microprocessor-controlled therapeutic and patterned functional electrical stimulation

Weingarden H.P., Zeilig G., Heruti R., Shemesh Y., Ohry A., Dar A., Katz D., Nathan R., and Smith A. (1998) Hybrid functional electrical stimulation orthosis system for the upper limb: effects on spasticity in chronic stable hemiplegia. Am. J. Phys. Med. Rehabil. 77, 276-281.
Abstract: A new hybrid functional electrical stimulation orthosis system for the upper limb has been designed to allow for ease of use in the home as a daily treatment modality, as well as offer the opportunity for function enhancement. In a pilot study, the system was used by ten patients with chronic stable hemiparesis secondary to cerebral vascular accident and head injuries. The patients were referred by their treating physicians or therapists after meeting the inclusion criteria of good general health, being greater than one year after head injury, or being ten months post-stroke, with no observed neurologic changes in the prior six weeks. Each of these patients had received prolonged physical therapy, either continuous from the initial inpatient rehabilitation treatment or on an intermittent basis over a period of years. The baseline status for factors related to increased muscle tone, i.e., passive range of motion at the wrist and elbow, posture at rest, posture immediately following activity, and spasticity were quantified before the treatment protocol with the functional electrical stimulation orthosis. Active range of motion and tests of functional use of the involved upper limb were also assessed. The patients were instructed in the protocol, trained in the use of the system, and then used the electrical orthosis at home for up to several hours per day. Follow-up assessments were at six months. A statistically significant improvement was noted in all muscle tone/spasticity parameters measured. A separate report will describe the effects on voluntary motion and functional capabilities

Winchester P., Montgomery J., Bowman B., and Hislop H. (1983) Effects of feedback stimulation training and cyclical electrical stimulation on knee extension in hemiparetic patients. Phys. Ther. 63, 1096-1103.
Abstract: Positional feedback stimulation training and cyclical electrical stimulation were used in combination as a treatment for facilitating knee extension in hemiparetic patients. Forty adult hemiparetic patients who demonstrated minimal active control of their quadriceps femoris muscles were randomly assigned to control or study groups. The control patients received a program of physical therapy, and the study patients received the positional feedback stimulation training in addition to their therapy program. The stimulation training provided the patient with immediate

auditory and visual feedback of his changing joint angle while he voluntarily extended his knee. When the patient reached a near maximal extension effort, electrical stimulation of the quadriceps femoris muscle was automatically triggered, completing the patient's available range of motion in extension. The stimulation training was supplemented with two hours of cyclical electrical stimulation daily. At the end of four weeks, analysis revealed a statistically significant increase in knee extension torque and active synergistic range of motion in the study group. No change was noted in their ability to extend their knees using isolated quadriceps femoris muscle control. This study suggests that positional feedback stimulation training is effective when used to augment a facilitation program for improving knee extension control in hemiparetic patients

Young R.R., Wiegner A.W. (1987) Spasticity. *Clin Orthop* 219, 50-62.