Electrical Stimulation And Range Of Motion: References

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

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

Bajuk S., Jelnikar T., and Ortar M. (1996) Rehabilitation of patient with brachial plexus lesion and break in axillary artery. Case study. J. Hand Ther. 9, 399-403.
Abstract: This paper describes the physiotherapy and occupational therapy used in treating a 74-year-old woman with a left brachial plexus lesion, a break in the axillary artery, dislocation of the acromioclavicular joint, a broken scapula and clavicula, serial left rib fractures, and lacerations on the upper and lower arm. After testing the patient, the following goals were set: reduce pain, soften scar tissue, and improve joint motion, muscle strength, and functionality of the hand. A 12- month outpatient program was used. Various analgesics were used to reduce pain, and a special aid was made to unweight the shoulder and elbow joints. Physiotherapy included kinesiotherapy, audiovisual biofeedback, electrical stimulation, friction massage, and

lymph drainage. Occupational therapy included active functional exercises and re-education. As a result of this program, the patient no longer had pain, passive range of motion was close to normal, active motion where present was improved, swelling was reduced, and the hand became functional again. Complex physiotherapy, occupational therapy, and the patient's motivation resulted in the rehabilitation of severe trauma of the hand

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

Baker L.L. and Parker K. (1986) Neuromuscular electrical stimulation of the muscles surrounding the shoulder. Phys. Ther. 66, 1930-1937.
Abstract: Neuromuscular electrical stimulation (NMES) can be used to augment range-of-motion, strengthening, and facilitation treatment programs of the muscles surrounding the shoulder. The purposes of this article are 1) to describe the uses of NMES around the shoulder joint as developed through our clinical use and 2) to detail the effects of an NMES program on chronic shoulder subluxation as determined by a clinical study. Because of the complexities of this multiarticular joint, NMES is most useful in the initial phase of the ROM, and stimulated contractions are compromised, relatively, as the humerus moves above the 90-degree horizontal

plane. The use of NMES to provide scapular stabilization often entails unwanted alteration of the pressures on the spinal column, occasionally making the treatment program unusable. Electrical stimulation to prevent or correct shoulder subluxation, especially in the neurologically involved patient, provides the therapist with a powerful new treatment technique. In a group of stroke patients, shoulder subluxation was reduced significantly (p less than .05) at the completion of a six-week NMES program. Some of the problems, and possible solutions, unique to the development of electrical stimulation programs for the shoulder muscles are discussed

Bilko T.E., Paulos L.E., Feagin J.A., Jr., Lambert K.L., and Cunningham H.R. (1986) Current trends in repair and rehabilitation of complete (acute) anterior cruciate ligament injuries. Analysis of 1984 questionnaire completed by ACL Study Group. Am. J. Sports Med. 14, 143-147.
Abstract: Results of a 21 question survey, taken at the ACL Study Group meeting in 1984, present a composite picture of current practices in ACL reconstruction and rehabilitation. Forty-four of the 50 questionnaires were returned. Responses represented views from knee surgeons in the United States, Canada, Australia, Sweden, and Switzerland. These results were compared with a report of a 1980 international survey in which views of 40 knee experts from the United States, Canada, England, France, and Sweden were summarized. Questions on the two surveys were similar, particularly about rehabilitation. Although the time span between the two surveys was only 4 years, we can see both consistencies and changes. Responses about length of time between ACL repair and full range of motion (by 6 months) were essentially the same (88% in 1980, and 86.4% in 1984). However, changes were evident in length of immobilization (longer in 1980) and prescribing isometric contractions of quadriceps 1st week postoperatively (more frequently in 1980). Surgeons allowed patients to return to full activity sooner in 1980 than in 1984. Electrical stimulation was being used more frequently in 1984, and apparently the practice of simultaneous hamstring and quadriceps contraction has come into prominence since 1980 as it was not mentioned in the first survey. In 1984, 50% of the respondents indicated they prescribed it. Since standardized reporting systems are not established, we cannot do reliable statistical analyses on large samples. At the present time, making surveys with responses from similar groups every few years is the best available way to capture trends in treatment of ACL injuries

Bowman B.R., Baker L.L., and Waters R.L. (1979) Positional feedback and electrical stimulation: an automated treatment for the hemiplegic wrist. Arch. Phys. Med. Rehabil. 60, 497-502.
Abstract: Positional feedback (PF) and electrical stimulation were combined in a new treatment modality for facilitating wrist extension in stroke patients. Thirty adult hemiparetic patients lacking normal voluntary wrist extension were randomly placed in control and study groups. The control group received conventional therapy while the study group received positional feedback stimulation training (PFST) in addition to conventional treatment. At the end of the 4-week program, study patients showed a 280% increase in isometric extension torque when the wrist was positioned in 30 degrees of extension and 70% increase when positioned in 30 degrees of flexion. Control patients showed no significant changes in torque. Study patients made an average 200% gain in selective range of motion over their starting levels while controls made only a 50% increase. Treatment using automated PFST equipment

allows controlled repetitive isotonic exercise and facilitation of wrist extension without continuous one-on-one therapist/patient supervision

Bremner L.A., Sloan K.E., Day R.E., Scull E.R., and Ackland T. (1992) A clinical exercise system for paraplegics using functional electrical stimulation. Paraplegia 30, 647-655.
Abstract: A low cost clinical exercise system was developed for the spinal cord injured, based on a bicycle ergometer and electrical stimulation. A pilot project was conducted, using the system, to examine the effects of stimulation induced cycling in long term paraplegics. The project comprised 2 phases of exercise, a strengthening phase involving a 12 week programme of electrical stimulation to the quadriceps and hamstrings and a 12 week cycling phase. Physiological, morphological and biochemical parameters were measured for each subject, at the beginning of the programme and following each phase. Results showed that a programme of stimulation induced lower limb exercise increased the exercise tolerance of all patients, as determined by a progressive increase in exercise time, cycling rate and exercise load. The enhanced exercise tolerance was a result of increases in local muscle strength and endurance. Increases in thigh muscle area and joint range of motion were recorded and all incomplete subjects reported an improvement in functional capabilities and general wellbeing

Bryden A.M., Memberg W.D., and Crago P.E. (2000) Electrically stimulated elbow extension in persons with C5/C6 tetraplegia: a functional and physiological evaluation. Arch. Phys. Med. Rehabil. 81, 80-88.
Abstract: OBJECTIVE: To measure the effect of electrically stimulated triceps on elbow extension strength, range of motion, and the performance of overhead reaching tasks. SETTING: Clinical research laboratory. PARTICIPANTS: Four individuals with spinal cord injuries at the C5 or C6 motor level. INTERVENTIONS: The participants, who already had an implanted upper extremity neuroprosthesis, were provided with elbow extension through functional electrical stimulation (FES) of the triceps brachii. MAIN OUTCOME MEASURES: Comparisons of stimulated elbow extension to voluntary elbow extension: (1) evaluations of impairment such as range of motion and strength; (2) performance of a set of functional overhead reaching tasks that required elbow extension; (3) a usage survey (conducted by telephone) to examine use of triceps stimulation in the home and community. RESULTS: All participants achieved greater range of motion and strength of elbow extension with stimulated triceps versus without. Overall functional task performance improved in 100% of the tasks tested for all but one participant, who showed improvement in 60% of the tasks. Participants reported using the triceps in at least one activity for at least 90% of the days the neuroprosthesis was donned

Campbell J.M. and Meadows P.M. (1992) Therapeutic FES: from rehabilitation to neural prosthetics. Assist. Technol. 4, 4-18.
Abstract: The purpose of this paper is to review the therapeutic applications of electrical stimulation and to focus on functional neuromuscular electrical stimulation (FES), which is the production of useful muscle contractions for joint stability and limb movement. The use of FES to improve patient function during the recovery period after illness or injury and the transition to FES neural prosthetic systems for patients who do not fully recover will be discussed. Emphasis will be given to the maintenance of posture and the production of purposeful movement from the perspective of technologies and clinical strategies that are available today and from

the perspective of those technologies that have the potential for transfer to community health care in the near future

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

Carroll S.G., Bird S.F., and Brown D.J. (1992) Electrical stimulation of the lumbrical muscles in an incomplete quadriplegic patient: case report. Paraplegia 30, 223-226.
Abstract: The increasing number of incomplete cervical spinal cord injuries means that more attention needs to be focused on the rehabilitation of the incomplete quadriplegic hand. A case study, describing the application of electrical stimulation for strengthening the paretic lumbrical muscles, is presented. A 2 week strengthening program resulted in a 33% increase in the force produced by the lumbrical muscles. No loss of strength had occurred 4 weeks after cessation of the treatment. The magnitude and speed of this result should be of interest to those clinicians who seek to maximise patient independence in minimal time

Chantraine A., Baribeault A., Uebelhart D., and Gremion G. (1999) Shoulder pain and dysfunction in hemiplegia: effects of functional electrical stimulation. Arch. Phys. Med. Rehabil. 80, 328-331.
Abstract: OBJECTIVE: To determine the influence of functional electrical stimulation (FES) on subluxation and shoulder pain in hemiplegic patients. DESIGN: Controlled study of 24 months' duration beginning in the first month after onset of stroke. SUBJECTS AND SETTING: One hundred twenty hemiplegic patients with both subluxed and painful shoulder were followed for rehabilitation before and after discharge between 1989 and 1993. All subjects received conventional rehabilitation based on the Bobath concept. In addition, patients were alternately assigned to a control group or to receive additional FES for 5 weeks on muscles surrounding their subluxed and painful shoulder. MAIN MEASURES: Clinical examinations, including range of motion, pain assessment, and x-rays, were performed at the start of the study, between the second and fourth weeks after onset of stroke, and subsequently at 6, 12, and 24 months. RESULTS: The FES group showed significantly more improvement than the control group in both pain relief (80.7% vs. 55.1%, $p<.01$) and reduction of subluxation (78.9% vs. 58.6%, $p<.05$). Furthermore, recovery of arm motion appeared to be significantly improved in the FES group (77.1% vs. 60.3% in the control group, $p<.01$). CONCLUSION: The FES program was significantly effective in reducing the severity of subluxation and pain and possibly may have facilitated recovery of the shoulder function in hemiplegic patients

Crago P.E., Memberg W.D., Usey M.K., Keith M.W., Kirsch R.F., Chapman G.J., Katorgi M.A., and Perreault E.J. (1998) An elbow extension neuroprosthesis for individuals with tetraplegia. IEEE Trans. Rehabil. Eng 6, 1-6.
Abstract: Functional electrical stimulation (FES) of the triceps to restore control of elbow extension was integrated into a portable hand grasp neuroprosthesis for use by people with cervical level spinal cord injury. An accelerometer mounted on the upper arm activated triceps stimulation when the arm was raised above a predetermined threshold angle. Elbow posture was controlled by the subjects voluntarily flexing to counteract the stimulated elbow extension. The elbow moments created by the stimulated triceps were at least 4 N.m, which was sufficient to extend the arm against gravity. Electrical stimulation of the triceps increased the range of locations and orientations in the workspace over which subjects could grasp and move objects. In addition, object acquisition speed was increased. Thus elbow extension enhances a person's ability to grasp and manipulate objects in an unstructured environment

Davis R., Houdayer T., Andrews B., and Barriskill A. (1999) Paraplegia: prolonged standing using closed-loop functional electrical stimulation and Andrews ankle-foot orthosis. Artif. Organs 23, 418-420.
Abstract: One T10 paraplegic male (CS) implanted in 1991 with a Nucleus FES-22 stimulator has been able to achieve closed-loop standing for 1 h. The knee angles are monitored by electrogoniometers, resulting in the quadriceps stimulation time being less than 10%. Stance stability is achieved by the Andrews anterior ankle-foot orthosis (AFO). The use of accelerometers for trunk inclination and vertical acceleration during controlled stand-to-sit, diminishes slamming onto the seat. CS does one- handed tasks with objects of 2.2 kg. In another T10 paraplegic male (FR), surface stimulation was applied over 1.5 years to both femoral nerves at the groin for conditioning and prolonged standing. With quadricep conditioning, 55 Nm at 45 degrees of knee flexion is produced. With the AFO and knee monitoring, FR can stand uninterrupted for up to 70 min and perform one-handed tasks. In August 1998, he was implanted with the multifunctional Praxis FES 24-A stimulator for restoration of limb movements, bladder and bowel function, and pressure sore prevention

Davis S.E., Mulcahey M.J., Smith B.T., and Betz R.R. (1999) Outcome of functional electrical stimulation in the rehabilitation of a child with C-5 tetraplegia. J. Spinal Cord. Med. 22, 107-113.
Abstract: Hand function was provided for a six-year-old child with C-5 American Spinal Injuries Association (ASIA) classification-A tetraplegia through a percutaneous intramuscular (i.m.) functional electrical stimulation (FES) system. In conjunction with implantation of 10 percutaneous i.m. electrodes for provision of grasp and release of her right hand, reconstructive surgery was performed to provide upper extremity positioning to optimize hand use. The subject participated in FES training over a nine-week period for approximately five hours weekly, with an additional five hours each week dedicated to exercise and conditioning of her arm muscles. Physical and functional assessments included range of motion (ROM), manual muscle testing (MMT), activities of daily living (ADL) abilities and the Canadian Occupational Performance Measure (COPM), used to evaluate the effect of stimulated hand function and surgical reconstruction on functional ability. These were conducted prior to FES and surgery and repeated after rehabilitation training. With rehabilitation and training, the child was able to control her FES system. Physical assessments revealed increased strength of both shoulders and more useful range of arm

movement. Functional assessments show that the FES system enabled her to perform age-appropriate ADL that previously were achievable only with physical assistance. Her overall level of independence in ADL ability increased, as did self-rated levels of satisfaction and performance on chosen activities. Positive gains demonstrated here suggest the need for further studies of FES systems in young children with SCI

Draper V. and Ballard L. (1991) Electrical stimulation versus electromyographic biofeedback in the recovery of quadriceps femoris muscle function following anterior cruciate ligament surgery. Phys. Ther. 71, 455-461.
Abstract: Both electrical stimulation and electromyographic biofeedback have been shown to be more effective than voluntary isometric exercise alone in the recovery of quadriceps femoris muscle force following anterior cruciate ligament (ACL) reconstruction. In a comparison of these two modalities, 30 patients with ACL reconstruction were randomly assigned to either a group receiving electrical stimulation in conjunction with voluntary isometric exercise or a group receiving biofeedback in conjunction with voluntary isometric exercise. Following 6 weeks of a rehabilitative exercise protocol, the quadriceps femoris muscle isometric peak torque in the operative limb was compared with that in the nonoperative limb. A t test of independent samples indicated that the biofeedback group recovered a significantly greater percentage of their nonoperative limb's peak torque than did the electrical stimulation group. Measurements of active knee extension were taken at weeks 1, 2, 4, and 6 of the exercise program. A two-way analysis of variance (groups x weeks) indicated no significant difference between the rate at which each group recovered full active extension. The authors concluded that biofeedback is more effective than electrical stimulation in facilitating the recovery of peak torque and that biofeedback is comparable to electrical stimulation in the recovery of active knee extension

Faghri P.D., Rodgers M.M., Glaser R.M., Bors J.G., Ho C., and Akuthota P. (1994) The effects of functional electrical stimulation on shoulder subluxation, arm function recovery, and shoulder pain in hemiplegic stroke patients. Arch. Phys. Med. Rehabil. 75, 73-79.
Abstract: The purpose of this study was to evaluate the effectiveness of a functional electrical stimulation (FES) treatment program designed to prevent glenohumeral joint stretching and subsequent subluxation and shoulder pain in stroke patients. Twenty-six recent hemiplegic stroke patients with shoulder muscle flaccidity were randomly assigned to either a control group (n = 13; 5 female, and 8 male) or experimental group (n = 13; 6 female, and 7 male). Both groups received conventional physical therapy. The experimental group received additional FES therapy where two flaccid/paralyzed shoulder muscles (supraspinatus and posterior deltoid) were induced to contract repetitively up to 6 hours a day for 6 weeks. Duration of both the FES session and muscle contraction/relaxation ratio were progressively increased as performance improved. The experimental group showed significant improvements in arm function, electromyographic activity of the posterior deltoid, range of motion, and reduction in subluxation (as indicated by x-ray) compared with the control group. We concluded that the FES program was effective in reducing the severity of shoulder subluxation and pain, and possibly facilitating recovery of arm function

Franco J.C., Perell K.L., Gregor R.J., and Scremin A.M. (1999) Knee kinetics during functional electrical stimulation induced cycling in subjects with spinal cord injury: a

preliminary study. J. Rehabil. Res. Dev. 36, 207-216.
Abstract: The purpose of this preliminary study was to describe pedal effectiveness parameters and knee-joint reaction forces generated by subjects with chronic spinal cord injury (SCI) during functional electrical stimulation (FES)-induced bicycling. Three male subjects (age 33-36 years old), who were post-traumatic SCI (ASIA-modified level A, level T4-C5) and enrolled in an FES rehabilitation program, signed informed consent forms and participated in this study. Kinematic data and pedal forces during bicycling were collected and effective force, knee-joint reaction forces, knee generalized muscle moments, and knee- joint power and work were calculated. There were three critical findings of this study: 1) pedaling effectiveness was severely compromised in this subject population as indicated by a lack of overall positive crank work; 2) knee-joint kinetics were similar in magnitude to data reported for unimpaired individuals pedaling at higher rates and workloads, suggesting excessive knee-joint loading for subjects with SCI; and 3) shear reaction forces and muscle moments were opposite in direction to data reported for unimpaired individuals, revealing an energetically unfavorable knee stabilizing mechanism. The critical findings of this study suggest that knee-joint kinetics may be large enough to produce a fracture in the compromised lower limbs of individuals with SCI

Gotlin R.S., Hershkowitz S., Juris P.M., Gonzalez E.G., Scott W.N., and Insall J.N. (1994) Electrical stimulation effect on extensor lag and length of hospital stay after total knee arthroplasty. Arch. Phys. Med. Rehabil. 75, 957-959.
Abstract: The effects of electrical stimulation in conjunction with traditional physical therapy, on knee extensor lag and length of hospital stay among patients recovering from total knee arthroplasty were assessed. Forty patients who underwent total knee replacement (TKR) were randomly assigned to either an electrical stimulation group (16 females, 5 males), or a control group (15 females, 4 males). Both groups received conventional physical therapy including continuous passive motion (CPM) to the affected limb, ambulation training, range of motion exercises, and activities of daily living (ADL) training. The experimental group additionally received electrical stimulation during CPM treatment. Experimental group subjects reduced their extensor lag from 7.5 to 5.7 degrees, whereas control group extensor lag increased from 5.3 to 8.3 degrees. These trends were significantly different ($p < .01$). Rehabilitation discharge criteria were reached in 6.7 days in the experimental group and 7.4 days in the control group. These differences were also significant ($p < .05$). The results of this study indicate that the application of electrical stimulation during recovery from TKR can effectively reduce extensor lag and decrease the length of hospital stay

Grill J.H. and Peckham P.H. (1998) Functional neuromuscular stimulation for combined control of elbow extension and hand grasp in C5 and C6 quadriplegics. IEEE Trans. Rehabil. Eng 6, 190-199.
Abstract: Spinal cord injury sustained at the C5/C6 level leaves an individual without voluntary control of the muscles of the forearm, hand, or of the elbow extensors. The objective of this research project was to integrate functional neuromuscular stimulation (FNS) control of elbow extension with a previously developed system that provides hand grasp in order to increase the working volume in space in which users can perform functional tasks. Elbow extension control was achieved by detecting the position of the arm in space and determining the magnitude of the gravitational moment acting to oppose extension. An accelerometer was used as the command control source, and this sensor was placed over the ulna near the elbow joint to

detect static (gravitational) acceleration, and therefore the gravitational moment acting about the elbow joint. This value determined the level of electrical stimulation required to activate the triceps muscles to full extension against these forces. Combined FNS control of elbow extension and hand grasp was implemented in two quadriplegic subjects. Both subjects were able to reach and grasp objects at locations in space which were unattainable without triceps activation

Handa I., Matsushita N., Ihashi K., Yagi R., Mochizuki R., Mochizuki H., Abe Y., Shiga Y., Hoshimiya N., Itoyama Y., and . (1995) A clinical trial of therapeutic electrical stimulation for amyotrophic lateral sclerosis. Tohoku J. Exp. Med. 175, 123-134.
Abstract: This paper describes the effects of therapeutic electrical stimulation (TES) on the wasting muscles in a patient with amyotrophic lateral sclerosis. The patient is a 47-year-old male, and he has a history of progressive muscle weakness and atrophy, affected more in the right side. Percutaneously indwelling intramuscular electrodes were implanted to the affected muscles in the right upper and lower extremities but no electrode in the corresponding left region. Within a month of TES therapy, a rapid improvement of extremity motion appeared in the TES treated side. Long-term application of TES more than 3 months increased the strength of the muscle which had been evidently weaker than the non- treated side. CT findings of both the upper and lower extremities with TES therapy showed an increase in the density and a reduction in the moth-eaten image. An increase in the thickness of the muscles was also observed in the TES treated side while deterioration was observed in the muscles on the non-treated side

Herbison G.J., Jaweed M.M., and Ditunno J.F., Jr. (1983) Exercise therapies in peripheral neuropathies. Arch. Phys. Med. Rehabil. 64, 201-205.
Abstract: The treatment of peripheral neuropathies should be aimed at maintaining the range of motion of the joints, re-educating the patient in skilled activities and optimizing the recovery of strength. Many techniques have been described to substitute for, to strengthen and to improve the function of residual innervated muscle; however, not all of these techniques are of unquestioned value. Specifically, electrical stimulation does not appear to enhance reinnervation of totally denervated muscle. Similarly, overstretching weakened muscle may impair the use of paretic muscle. Because overwork may damage partially denervated muscle, brief isometric or isotonic contractions may be more beneficial for increasing strength than a program of habitual exhausting activities

Keith M.W., Kilgore K.L., Peckham P.H., Wuolle K.S., Creasey G., and Lemay M. (1996) Tendon transfers and functional electrical stimulation for restoration of hand function in spinal cord injury. J. Hand Surg. [Am.] 21, 89-99.
Abstract: Spinal cord injury at the C5 and C6 level results in loss of hand function. Electrical stimulation of paralyzed muscles is one approach that has demonstrated significant capacity for restoring grasp and release function. One potential limitation of this approach is that key muscles for stimulation may have lower motor neuron damage, rendering the muscles unexcitable. We have used surgical modification of the biomechanics of the hand to overcome this limitation. Tendon transfer of paralyzed but lower motor neuron intact muscles can compensate for potential function lost owing to muscles with lower motor neuron damage. Such procedures have been performed to provide finger extension, thumb extension, finger flexion, and wrist extension. Additional surgical procedures have been performed to enhance the function provided with electrical stimulation. These are side-to-side

synchronization of the finger flexor and extensor tendons, the flexor digitorium superficialis Zancolli-lasso procedure, and thumb interphalangeal joint arthrodesis. These procedures have been performed in 11 patients with C5 and C6 level spinal injuries and functional electrical stimulation neuroprostheses. In these patients, 41 different functional electrical stimulation-related procedures were performed and 38 gave the desired result after surgery. One procedure resulted in no increase or decrease in function or muscle output, and two procedures resulted in a decrease in muscle force or joint range of motion. The issues that must be considered in performing functional electrical stimulation-related tendon transfers are discussed

Laska T. and Hannig K. (2001) Physical therapy for spinal accessory nerve injury complicated by adhesive capsulitis. Phys. Ther. 81, 936-944.
Abstract: BACKGROUND AND PURPOSE: The authors found no literature describing adhesive capsulitis as a consequence of spinal accessory nerve injury and no exercise program or protocol for patients with spinal accessory nerve injury. The purpose of this case report is to describe the management of a patient with adhesive capsulitis and spinal accessory nerve injury following a carotid endarterectomy. CASE DESCRIPTION: The patient was a 67-year-old woman referred for physical therapy following manipulation of the left shoulder and a diagnosis of adhesive capsulitis by her orthopedist. Spinal accessory nerve injury was identified during the initial physical therapy examination, and a program of neuromuscular electrical stimulation was initiated. OUTCOMES: The patient had almost full restoration of the involved muscle function after 5 months of physical therapy. DISCUSSION: This case report illustrates the importance of accurate diagnosis and suggests physical therapy intervention to manage adhesive capsulitis as a consequence of spinal accessory nerve injury

Lehmann T.R., Russell D.W., Spratt K.F., Colby H., Liu Y.K., Fairchild M.L., and Christensen S. (1986) Efficacy of electroacupuncture and TENS in the rehabilitation of chronic low back pain patients. Pain 26, 277-290.
Abstract: Fifty-four patients treated in a 3-week inpatient rehabilitation program were randomly assigned to and accepted treatment with electroacupuncture (n = 17), TENS (low intensity transcutaneous nerve stimulation, n = 18), and TENS dead-battery (placebo, n = 18). Outcome measures included estimates of pain (on a Visual Analogue Scale) and disability by both physician and patient, physical measures of trunk strength and spine range of motion, as well as the patient's perceptions of the relative contribution of the education, exercise training, and the electrical stimulation. Analyses of variance were utilized to determine effects of treatment (electroacupuncture, TENS, placebo) across time (admission, discharge, and return) for the outcome measures. There were no significant differences between treatment groups with respect to their overall rehabilitation. All 3 treatment groups ranked the contribution of the education as being greater than the electrical stimulation. However, the electroacupuncture group consistently demonstrated greater improvement on the outcome measures than the other treatment groups. For the visual analogue scale measure of average pain, there was a statistical trend at the return visit suggesting that the acupuncture group was experiencing less pain

Lieber R.L., Amiel D., Kaufman K.R., Whitney J., and Gelberman R.H. (1996) Relationship between joint motion and flexor tendon force in the canine forelimb. J. Hand Surg. [Am.] 21, 957-962.
Abstract: To increase in vivo tendon force and gliding after flexor tendon repair, a

variety of modifications to the methods by which protective passive motion is administered have been advocated. To determine the relationship between the prime variables, wrist and digital position, muscle activation, and in vivo tendon force, a clinically relevant canine model was developed. Force was measured in the flexor tendon during several joint manipulation paradigms: single-finger flexion- extension with the wrist flexed (group 1F), single-finger flexion- extension with the wrist extended (group 1E), four-finger flexion- extension with the wrist flexed (group 4F), four-finger flexion- extension with the wrist extended (group 4E), and synergistic wrist and finger motion where wrist extension and finger flexion were performed simultaneously, followed by wrist flexion and finger extension (group SYN). In addition, tendon force was measured during electric stimulation of the proximal flexor muscle mass. Passive tendon force with the wrist extended (groups 1E and 4E) was two to three times greater than that measured with the wrist flexed, independent of the number of digits moved. With the wrist extended, peak tendon force reached 1,997 g +/- 194 g during single-digit manipulation (group 1E), compared to only 853 g +/- 104 g with the wrist flexed during the same maneuver (group 1F). Statistical comparison between means revealed that groups 1E and 4E were significantly different from groups 1F, 4F, and SYN ($p < .005$). There were no significant differences between groups 1E and 4E or between groups 1F, 4F, and SYN ($p > .200$). Active muscle force elicited by electrical stimulation and passive force varied dramatically as the wrist was flexed from full extension 3460 g +/- 766 g to full flexion 427 g +/- 239 g ($p < .001$). Simultaneously, passive tension decreased from 940 g +/- 143 g with wrist extended to 76 g +/- 37 g with the wrist flexed. These data indicate that wrist position has the greatest effect on flexor tendon force during motions that are commonly used to rehabilitate flexor tendon repairs. Thus, if force is to be controlled during passive motion, wrist-joint angle will have the dominant effect, while the number of digits manipulated will have much less of an effect. If the clinical goal is to minimize tendon force, rehabilitation could be carried out with the wrist flexed, whereas if the goal is to increase tendon force, rehabilitation could include exercise programs that use a greater degree of wrist extension

Milne R.J., Dawson N.J., Butler M.J., and Lippold O.C. (1985) Intramuscular acupuncture-like electrical stimulation inhibits stretch reflexes in contralateral finger extensor muscles. Exp. Neurol. 90, 96-107.
Abstract: Electro-acupuncture is one of many physical measures used to relieve musculoskeletal pain and to improve the associated restricted range of motion. Experiments were designed to determine whether or not acupuncture-like stimulation inhibits stretch reflexes in an arm extensor muscle in human volunteers. Surface electromyographic recordings were made on the right extensor digitorum communis muscle and averaging techniques were used to study the reflex responses to brief deflection of the finger with a solenoid-driven probe. The ratio M1:M2 of two components of the reflex was reduced during continuous acupuncture-like stimulation of the contralateral first dorsal interosseus and extensor digitorum communis muscles near their motor points (acupuncture points LI 4 and LI 11). Concomitant changes in skin temperature were observed on the forehead and in the arm in which acupuncture-like stimulation was used. In control experiments, when the acupuncture needles were inserted subcutaneously and stimulated with the same current parameters at distinctly uncomfortable intensities, no change in the reflexes occurred. These findings show that acupuncture- like stimulation exerts physiologic effects on the central nervous system, mediated presumably by muscle

afferent fibers. The effects may be relevant to relief of muscle spasm and musculoskeletal pain, and restoration of mobility

Mulcahey M.J., Betz R.R., Smith B.T., Weiss A.A., and Davis S.E. (1997) Implanted functional electrical stimulation hand system in adolescents with spinal injuries: an evaluation. Arch. Phys. Med. Rehabil. 78, 597-607.
Abstract: OBJECTIVE: To study the utility and functional benefits of an implanted functional electrical stimulation (FES) system for hand grasp and release in adolescents with tetraplegia secondary to spinal cord injuries. DESIGN: Intervention study with before-after trial measurement with each subject as his or her own control. SETTING: Nonprofit pediatric orthopedic rehabilitation facility specializing in spinal cord injury. PARTICIPANTS: A convenience sample of five adolescents between 16 and 18 years of age with C5 or C6 level tetraplegia at least 1 year after traumatic spinal cord injury. Key muscles for palmar and lateral grasp and release were excitable by electrical stimulation. INTERVENTIONS: A multichannel stimulator/receiver and eight electrodes were surgically implanted to provide stimulated palmar and lateral grasp and release. In conjunction with implantation of the FES hand system, surgical reconstruction in the form of tendon transfers, tendon lengthenings and releases, and joint arthrodeses was performed to augment stimulated hand function. Rehabilitation of the tendon transfers and training in the use of the FES hand system were provided. MAIN OUTCOME MEASURES: Measurements of pinch and grasp force, the Grasp and Release Test (GRT), and an assessment of six activities of daily living (ADL) were administered before implantation of the FES hand system and at regular follow-up intervals. Results of the stimulated response of individual muscles and surgical reconstruction were evaluated using standard and stimulated muscle testing techniques and standard assessment of joint range of motion. All subjects completed followup testing. RESULTS: Lateral and palmar forces were significantly greater than baseline forces ($p = .043$). Heavy objects on the GRT could only be manipulated with FES, and FES increased the level of independence in 25 of 30 ADL comparisons (5 subjects, 6 activities) as compared to baseline. After training, FES was preferred in 21 of 30 comparisons over the typical means of task completion. Of the 40 electrodes implanted, 37 continue to provide excellent stimulated responses and all of the implanted stimulators have functioned without problems. The surgical reconstruction procedures greatly enhanced FES hand function by either expanding the workspace in which to utilize FES (deltoid to triceps transfer), stabilizing the wrist (brachioradialis to wrist extensor transfer), or stabilizing joints (intrinsic tenodesis transfer, FPL split transfer). CONCLUSION: For five adolescents with tetraplegia, the combination of FES and surgical reconstruction provided active palmar and lateral grasp and release. Laboratory-based assessments demonstrated that the FES system increased pinch force, improved the manipulation of objects, and typically increased independence in six standard ADL as compared to pre-FES hand function. The study also showed that the five adolescents generally preferred FES for most of the ADL tested. Data on the benefits of the implanted FES hand system outside of the laboratory are needed to understand the full potential of FES

Pandyan A.D., Granat M.H., and Stott D.J. (1997) Effects of electrical stimulation on flexion contractures in the hemiplegic wrist. Clin. Rehabil. 11, 123-130.
Abstract: OBJECTIVE: To study the effects of electrical stimulation (ES) on flexion contractures in the hemiplegic wrist. DESIGN: The investigation was carried out following an OFF (two weeks with rehabilitation only)-- ON (two weeks with ES

treatment and rehabilitation)--OFF (two weeks rehabilitation only) fixed protocol. SETTING: A stroke ward and an outpatient stroke service. SUBJECTS: Eleven hemiplegic subjects with reduced range of extension and increased resistance to passive movement at the wrist. MAIN MEASURE: Quantitative measures of the hemiplegic posture at the wrist, passive range of extension and resistance to passive extension of the wrist. Measurements were taken at the start of the study and then at two-weekly intervals. Two extra measurements were taken at the end of the ON period. RESULTS: Following two weeks treatment with ES the posture of the wrist improved and the passive range of extension increased. However, there were no significant changes in the resistance to passive movement. These benefits appeared largely to be lost two weeks after ES was discontinued. CONCLUSIONS: Short-term ES gives temporary improvements in contractures at the wrist in poststroke hemiplegia

Popovic D., Stojanovic A., Pjanovic A., Radosavljevic S., Popovic M., Jovic S., and Vulovic D. (1999) Clinical evaluation of the bionic glove. Arch. Phys. Med. Rehabil. 80, 299-304.
Abstract: OBJECTIVE: Clinical evaluation of the Bionic Glove, a prototype of a new functional electrical stimulation device designed to improve the function of the paralyzed hand after spinal cord injury. PATIENTS: Twelve people with spinal cord injury at C5-C7 who had used the device 6 months or more. SETTING: Measurements were made at the Institute "Dr Miroslav Zotovic" in Belgrade as a part of a multicenter clinical trial. METHODS: Measures include Upper Extremity Function Test, Functional Independence Measure, and Quadriplegia Index of Function. RESULTS: The daily use of a Bionic Glove had two major effects: (1) increasing the power grasp; and (2) increasing the range of movements. Active force was significantly greater than passive tenodesis force, as shown in other studies. Most manual tasks improved significantly with the use of the assistive system, as judged by the time needed to complete a task or the subject's qualitative ratings of a task difficulty. Most subjects who retained some dexterity without the assistive system hesitated to use the assistive system to manipulate small objects. CONCLUSION: The Bionic Glove can significantly improve independence in people with C5-C7 spinal cord injury if their initial Functional Independence Measure and Quadriplegia Index of

Smith L.E. (1990) Restoration of volitional limb movement of hemiplegics following patterned functional electrical stimulation. Percept. Mot. Skills 71, 851-861.
Abstract: 24 hemiplegic patients completed patterned functional electrical stimulation (PFES) upon the afflicted arm and leg. The multichannel PFES program was mathematically derived from the EMG agonist/antagonist pattern recorded from each subject's unaffected limbs during a series of monitored, voluntary movements. The average improvement in volitional range of motion for the group's paralyzed limbs was 90% for the upper extremities and 69% for the lower extremities. For partially paralyzed limbs, there was an average increase in range of movement of 68% for the upper extremities and 26% for the lower extremities. These findings support the relearning-based, PFES open-loop theory which uses individualized therapeutic PFES-derived from EMG coordination patterns modeled from specific, ballistic limb movements to rehabilitate patients who have been immobilized after stroke

Steadman J.R. (1982) Rehabilitation of skiing injuries. Clin. Sports Med. 1, 289-294.
Abstract: It is important to include psychological and physiologic rehabilitation in

addition to rehabilitation of the injured area. Motion that does not stress repairs of either ligament or bone is not contraindicated. Exercises that aggravate patellofemoral problems should be modified to avoid areas in the range of motion that cause crepitance or pain. The use of modalities such as electrical stimulation is an important adjunct. Exercisers that allow speed work-out and isolate the muscle group are helpful but not mandatory. Manual resistance can parallel each type of machine exercise. Ligaments that have been repaired should be allowed to mature prior to allowing subluxing stresses. Before resumption of skiing, reactive exercises should be done

Taylor P.N., Burridge J.H., Dunkerley A.L., Wood D.E., Norton J.A., Singleton C., and Swain I.D. (1999) Clinical use of the Odstock dropped foot stimulator: its effect on the speed and effort of walking. Arch. Phys. Med. Rehabil. 80, 1577-1583.
Abstract: OBJECTIVE: To assess the clinical effectiveness of the Odstock dropped foot stimulator by analysis of its effect on physiological cost index (PCI) and speed of walking. This functional electrical stimulation (FES) device stimulates the common peroneal nerve during the swing phase of gait. DESIGN: A retrospective study of patients who had used the device for 4 1/2 months. SUBJECTS: One hundred fifty-one patients with a dropped foot resulting from an upper motor neuron lesion. SETTING: A medical physics and biomedical engineering department of a district general hospital specializing in the clinical application of FES and a neurophysiotherapy department at a separate hospital. MAIN OUTCOME MEASURES: Changes in walking speed and effort of walking, as measured by PCI over a 10-meter course. RESULTS: There was a 92.7% compliance with treatment. Stroke patients showed a mean increase in walking speed of 27% ($p<.01$) and reduction in PCI of 31% ($p<.01$) with stimulation, and changes of 14% ($p<.01$) and 19% ($p<.01$), respectively, while not using the stimulator. Multiple sclerosis patients gained similar orthotic benefit but no "carry-over." CONCLUSIONS: The measured differences in walking with and without stimulation were statistically significant in the stroke and multiple sclerosis groups. In this study use of the stimulator improved walking. Those with stroke demonstrated a short-term "carry-over" effect

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

Werner S., Arvidsson H., Arvidsson I., and Eriksson E. (1993) Electrical stimulation of vastus medialis and stretching of lateral thigh muscles in patients with patello-femoral symptoms. Knee. Surg. Sports Traumatol. Arthrosc. 1, 85-92.
Abstract: Thirty patients with unilateral patello-femoral symptoms and a hypotrophic vastus medialis muscle were treated with transcutaneous electrical stimulation of the vastus medialis obliquus and stretching of the lateral thigh muscles twice daily for 10 weeks. Before and after treatment the position of the patella at fixed knee flexion angles and the area of the vastus medialis and vastus lateralis muscles were studied by computed tomography. Isokinetic quadriceps torque was registered with a Cybex II Dynamometer. An evaluation with a functional knee score was carried out. The healthy contralateral leg served as control in all the examinations. Clinically two-thirds of the patients had improved after 10 weeks of treatment and this improvement remained at follow-up 3.5 years later. The area of the vastus medialis and the quadriceps torque of the treated leg increased significantly, while the area of the vastus lateralis and the position of patella did not change. We conclude that transcutaneous electrical muscle stimulation of the vastus medialis and stretching of the lateral thigh muscles might be of benefit in patients with patello-femoral symptoms and a hypotrophic vastus medialis. An improvement after 10 weeks of treatment seems to predict a good long-term result

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

Wright P.A. and Granat M.H. (2000) Improvement in hand function and wrist range of motion following electrical stimulation of wrist extensor muscles in an adult with cerebral palsy. Clin. Rehabil. 14, 244-246.

Zizic T.M., Hoffman K.C., Holt P.A., Hungerford D.S., O'Dell J.R., Jacobs M.A., Lewis C.G., Deal C.L., Caldwell J.R., Cholewczynski J.G., and . (1995) The treatment of osteoarthritis of the knee with pulsed electrical stimulation. J. Rheumatol. 22, 1757-1761.

Abstract: OBJECTIVE. The safety and effectiveness of pulsed electrical stimulation was evaluated for the treatment of osteoarthritis (OA) of the knee. METHODS. A multicenter, double blind, randomized, placebo controlled trial that enrolled 78 patients with OA of the knee incorporated 3 primary efficacy variables of patients' pain, patients' function, and physician global evaluation of patients' condition, and 6 secondary variables that included duration of morning stiffness, range of motion, knee tenderness, joint swelling, joint circumference, and walking time. Measurements were recorded at baseline and during the 4 week treatment period. RESULTS. Patients treated with the active devices showed significantly greater improvement than the placebo group for all primary efficacy variables in comparisons of mean change from baseline to the end of treatment ($p < 0.05$). Improvement of > or = 50% from baseline was demonstrated in at least one primary efficacy variable in 50% of the active device group, in 2 variables in 32%, and in all 3 variables in 24%. In the placebo group improvement of > or = 50% occurred in 36% for one, 6% for 2, and 6% for 3 variables. Mean morning stiffness decreased 20 min in the active device group and increased 2 min in the placebo group ($p < 0.05$). No statistically significant differences were observed for tenderness, swelling, or walking time. CONCLUSION. The improvements in clinical measures for pain and function found in this study suggest that pulsed electrical stimulation is effective for treating OA of the knee. Studies for longterm effects are warranted