Electrical Stimulation And Muscle Performance

Badylak S.F., Hinds M., and Geddes L.A. (1990) Comparison of three methods of electrical stimulation for converting skeletal muscle to a fatigue resistant power source suitable for cardiac assistance. Ann. Biomed. Eng 18, 239-250.
Abstract: Twelve dogs were sorted into 3 equal groups, and the in-situ right latissimus dorsi muscle of each dog was stimulated via its motor nerve for a period of 6 weeks. The resulting isotonic contractions were used to pump fluid in an implanted, 2-chambered, compressible pouch system. Three methods of electrical stimulation were used: (a) continuous 2 sec- 1 single pulses that caused muscle twitching, (b) a 250 msec train of pulses (36 sec-1) that caused tetanic muscle contractions and was repeated every 2 sec for 15 min followed by a 15 min period of rest, and (c) alternating 15 min periods of the above 2 stimulation methods to cause alternating twitch and tetanic contractions. The 2 sec-1 twitch stimulation and the combined twitch/tetanic stimulation methods resulted in a 100% conversion to fatigue-resistant fibers within 6 weeks. Standardized muscle function tests were performed weekly. With the twitch stimulation (Method 1), the time to fatigue increased from 9 to 116 min (p less than 0.001), but fluid pumping ability of the muscle decreased substantially from 0.25 to 0.14 liters min-1 (p less than 0.05). With the intermittent tetanic stimulation (Method 2), the fatigue resistance increased only slightly from 7 to 11 minutes (p = NS), and pumping ability was unchanged. With the combined (twitch- tetanic) stimulation (Method 3), the time to fatigue increased from 9 to 107 min (p less than 0.001), and the pumping ability did not significantly change from 0.20 to 0.22 liters min-1 (p = NS). These results suggest that a combined electrical stimulation method which produces both twitches and tetanic contractions can achieve rapid fiber conversion and increased fatigue resistance without loss of muscle strength

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

Balogun J.A., Onilari O.O., Akeju O.A., and Marzouk D.K. (1993) High voltage electrical stimulation in the augmentation of muscle strength: effects of pulse frequency. Arch. Phys. Med. Rehabil. 74, 910-916.
Abstract: This study was designed to determine the effects of pulse frequency (20pps, 45pps, 80pps) on subjects' voltage tolerance, delayed muscle soreness, and

muscle strength gained following 6 weeks of electrical stimulation. Thirty healthy men (mean age = 22 years) were randomly assigned to three groups. Subjects in group 1 (n = 10), group 2 (n = 10), and group 3 (n = 10) had their right quadriceps femoris muscles electrically stimulated with a high-voltage pulsed galvanic stimulator present at pulse frequencies of 20pps, 45pps, and 80pps, respectively. The left limb of each subject served as the control. For all the groups, the duty cycle of the stimulator was set at 10 seconds on and 50 seconds off during the stimulation. At each training session, the maximal tolerable voltage for each subject was monitored. Ten maximum contractions was allowed at each training session. Muscle soreness perception was evaluated 48 hours after stimulation using a 10-point visual analog scale. Electrical stimulation was administered three times a week for 6 weeks. For each subject, the average voltage output and muscle soreness rating were computed at the end of each week. With a cable tensiometer, the knee extension isometric force of both limbs was evaluated before training and at the end of the second, fourth, and sixth weeks of the study and 3 weeks after training. Repeated measure's analysis of variance was used to determine significant differences in the dependent variables. The results showed that the maximum voltage tolerance, muscle soreness ratings, and muscle strength gained by the three groups are not significantly ($p > .05$) different.(ABSTRACT TRUNCATED AT 250 WORDS)

Belanger M., Stein R.B., Wheeler G.D., Gordon T., and Leduc B. (2000) Electrical stimulation: can it increase muscle strength and reverse osteopenia in spinal cord injured individuals? Arch. Phys. Med. Rehabil. 81, 1090-1098.
Abstract: OBJECTIVE: To study the extent to which atrophy of muscle and progressive weakening of the long bones after spinal cord injury (SCI) can be reversed by functional electrical stimulation (FES) and resistance training. DESIGN: A within-subject, contralateral limb, and matching design. SETTING: Research laboratories in university settings. PARTICIPANTS: Fourteen patients with SCI (C5 to T5) and 14 control subjects volunteered for this study. INTERVENTIONS: The left quadriceps were stimulated to contract against an isokinetic load (resisted) while the right quadriceps contracted against gravity (unresisted) for 1 hour a day, 5 days a week, for 24 weeks. MAIN OUTCOME MEASURES: Bone mineral density (BMD) of the distal femur, proximal tibia, and mid-tibia obtained by dual energy x-ray absorptiometry, and torque (strength). RESULTS: Initially, the BMD of SCI subjects was lower than that of controls. After training, the distal femur and proximal tibia had recovered nearly 30% of the bone lost, compared with the controls. There was no difference in the mid-tibia or between the sides at any level. There was a large strength gain, with the rate of increase being substantially greater on the resisted side. CONCLUSION: Osteopenia of the distal femur and proximal tibia and the loss of strength of the quadriceps can be partly reversed by regular FES-assisted training

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

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

Carmick J. (1993) Clinical use of neuromuscular electrical stimulation for children with cerebral palsy, Part 2: Upper extremity. Phys. Ther. 73, 514-522.
Abstract: This report, part 2 of a two-part case report on the clinical use of neuromuscular electrical stimulation (NMES) for children with cerebral palsy, documents the functional changes that occurred with the application of NMES to the upper extremity of two children, 1.6 and 6.7 years of age, with hemiplegia due to cerebral palsy. The NMES was used as an adjunct to a dynamic-systems, task-oriented physical therapy program. The youngest child showed immediate improvement in the ability to crawl and use both hands together. The older child demonstrated increased sensory awareness and use of the nonfunctional hand. Preliminary findings suggest that NMES may be a useful physical therapy tool for enhancing muscle strength increasing sensory awareness, and assisting motor learning and coordination

Chae J. and Yu D. (2000) A critical review of neuromuscular electrical stimulation for treatment of motor dysfunction in hemiplegia. Assist. Technol. 12, 33-49.
Abstract: The purpose of this review is to critically assess the clinical efficacy of neuromuscular electrical stimulation in treating motor dysfunction in hemiplegia. Three distinct applications are reviewed in the areas of motor relearning, shoulder dysfunction, and neuroprostheses. Assessment of clinical efficacy and recommendations on clinical implementation are based on the weight of published scientific evidence. With respect to motor relearning, evidence supports the use of neuromuscular electrical stimulation to facilitate recovery of muscle strength and coordination in hemiplegia. However, effects on physical disability are uncertain. With respect to shoulder dysfunction, neuromuscular electrical stimulation decreases shoulder subluxation, at least in the short term. However, effects on shoulder pain and disability are also uncertain. With respect to neuroprosthesis systems, clinically

deployable upper extremity systems must await the development of more sophisticated control methods and greater fundamental understanding of motor dysfunction in hemiplegia. The evidence for clinical feasibility of lower extremity neuroprostheses is stronger, and investigations on clinical efficacy should be pursued. In summary, the application of neuromuscular electrical stimulation for motor relearning and shoulder dysfunction are ready for more rigorous scientific and clinical assessment via large, multicenter, randomized clinical trials. However, additional investigations are needed to demonstrate the clinical feasibility of neuroprostheses applications

Delitto A., McKowen J.M., McCarthy J.A., Shively R.A., and Rose S.J. (1988) Electrically elicited co-contraction of thigh musculature after anterior cruciate ligament surgery. A description and single-case experiment. Phys. Ther. 68, 45-50.
Abstract: The purpose of this article is to describe a method for strengthening the quadriceps femoris muscle in a patient after anterior cruciate ligament (ACL) surgery. The method incorporates electrically elicited co-contraction of the quadriceps femoris and hamstring muscles. A single-case experimental design based on a split-middle (ABAB) technique was used to assess the effects of the systematic administration and withdrawal of electrical stimulation with respect to changes in knee isometric extension and flexion torque and circumferential measurements of the thigh in a patient six weeks after ACL reconstruction. Results show increases in extension and flexion torque and thigh circumferential measurements that are associated with both stimulation (treatment) phases in addition to a maintenance effect demonstrated during the withdrawal phase. In this patient, the technique appears to be effective in increasing muscle strength and circumferential measurements, particularly quadriceps femoris muscle torque. Implications and suggestions for future research are included

Delitto A. and Snyder-Mackler L. (1990) Two theories of muscle strength augmentation using percutaneous electrical stimulation. Phys. Ther. 70, 158-164.
Abstract: Electrical stimulation of muscle is a commonly used, well-substantiated strategy that physical therapists use to augment strength in patients with muscle weakness. Two distinctly different theories of strength augmentation using percutaneous muscle stimulation are presented. The first theory proposes that augmentation of muscle strength with electrically elicited muscle contractions occurs in a similar manner to augmentation of muscle strength with voluntary exercise. Electrically elicited muscle contractions of relatively high intensity with low numbers of repetitions strengthen muscle proportionally to the external load on the muscle in a manner that is equivalent to voluntary contraction. The second theory proposes that augmentation of muscle strength using percutaneous stimulation is fundamentally different from augmentation of strength with voluntary exercise. This theory uses the physiological differences between electrically elicited and voluntary contractions, such as the reversal of motor unit recruitment order, as a basis for argument. Both theories are partially substantiated using published literature. Strategies for testing both theories are also presented

Eriksson E., Haggmark T., Kiessling K.H., and Karlsson J. (1981) Effect of electrical stimulation on human skeletal muscle. Int. J. Sports Med. 2, 18-22.
Abstract: The acute and adaptive effects of electrical stimulation of the quadriceps muscle were investigated in healthy male volunteers. The acute effects, i.e., depletion of phosphagen and glycogen stores and formation of lactate as well as

decreases in certain enzyme activities, were similar to those found earlier for intense muscular exercise. Intermittent electrical stimulation for 4 to 5 weeks did not cause any significant changes in enzyme activities, muscle fiber characteristics, or mitochondrial properties. A 4-week period of electrical stimulation resulted in improvements of muscle strength comparable to the results of a corresponding program of voluntary training. However, the effects of electrical stimulation appeared more "position-specific" and less "speed-specific" than those of voluntary training with slow isokinetic contractions

**Girsch W., Bijak M., Heger G., Koller R., Lanmuller H., Mayr W., Thoma H., and Losert U. (1995) Monitoring of FES-induced muscle activity by continuous EMG-recording. Int. J. Artif. Organs 18, 340-344.
Abstract: Functional Electrical Stimulation (FES) requires information on the stimulated muscle for adjustment of the stimulation current, avoidance of muscle fatigue during the conditioning period and long term follow- up. Several applications of chronical FES are in clinical practice, but a system for direct registration of muscle activity under FES still does not exist. In six sheep the right Latissimus Dorsi Muscle (LDM) and Thoracodorsal Nerve were exposed. Stimulation electrodes were applied to each nerve and 3 EMG-applied sensing electrodes were placed into each LDM. The LDM tendon was connected to a force transducer. Burst stimulation was applied and the amplitude was increased from 0 to 4 mA in steps from burst to burst. EMG (M-wave) was amplified and recorded continuously via modified instrumentation amplifier, oscilloscope and tape recorder. Isometric muscle tension was recorded using force transducer, A/D interface and PC. Continuous EMG-recording was performed in all cases. Simultaneous recording of muscle tension and EMG revealed a close correlation (Irl=0.95, $p < 0.0001$) between the muscle strength and amplitude of the M-wave. Continuous recording of the EMG seems to be a reliable method for direct monitoring of the stimulated muscle. Three intramuscular electrodes can provide enough information to monitor FES induced muscle activity

Glanz M., Klawansky S., Stason W., Berkey C., and Chalmers T.C. (1996) Functional electrostimulation in poststroke rehabilitation: a meta- analysis of the randomized controlled trials. Arch. Phys. Med. Rehabil. 77, 549-553.
Abstract: OBJECTIVE: To assess the efficacy of functional electrical stimulation (FES) in the rehabilitation of hemiparesis in stroke. DESIGN: A meta- analysis combined the reported randomized controlled trials of FES in stroke, using the effect size method of Glass, and the DerSimonian- Laird Random Effects Method for pooling studies. SETTING: The included studies were published between 1978 and 1992. They were conducted in academic rehabilitation medicine settings. PATIENTS: In all included studies, patients were in poststroke rehabilitation. The mean time after stroke varied from 1.5 to 29.2 months. INTERVENTION: FES applied to a muscle or associated nerve in a hemiparetic extremity was compared to No FES. MAIN OUTCOME MEASURE: Change in paretic muscle force of contraction following FES was compared to change without FES. RESULTS: For the four included studies, the mean effect size was .63 (95% CI: .29, .98). This result was statistically significant ($p < .05$). CONCLUSION: Pooling from randomized trials supports FES as promoting recovery of muscle strength after stroke. This effect is statistically significant. There is a reasonable likelihood of clinical significance as well

Gordon T. and Mao J. (1994) Muscle atrophy and procedures for training after spinal cord injury. Phys. Ther. 74, 50-60.

Abstract: Functional electrical stimulation (FES) of paralyzed muscles holds promise as a strategy to assist patients in executing functional movements after spinal cord injuries. Muscle atrophy is one of the major problems that must be addressed for this approach to be successful. Loss of muscle mass may occur as a result of lesions to motoneurons in either the spinal cord or the central command pathway, or a combination of the two. For injuries to spinal motoneurons, muscle fibers undergo denervation atrophy. Damage to the central command pathway, on the other hand, results in disuse atrophy. In association with atrophy, the low contractile forces and inability of the muscles to sustain contractions are of direct therapeutic concern. In this review, methods aimed at recovery of function of paralyzed limbs by reducing susceptibility to fatigue and atrophy of paralyzed muscles are discussed. One is related to promoting nerve sprouting in partially denervated muscles to reinnervate muscle fibers and reverse denervation atrophy. The other regards training of paralyzed muscles to increase strength (muscle force) and endurance (fatigue resistance) by means of FES. Most training regimens with low-frequency FES increase muscle endurance. Efforts to design optimal regimens for increasing both muscle strength and endurance must involve consideration of several factors that are still controversial. These factors, which include muscle properties (such as fiber type composition and physiological type) and conditions imposed on the muscle (such as loading) during contractions elicited by FES, are discussed in detail

Gordon T. (1995) Fatigue in adapted systems. Overuse and underuse paradigms. Adv. Exp. Med. Biol. 384, 429-456.
Abstract: Alterations in structural and biochemical properties of muscles that underlie physiological parameters of contractile force, speed and fatigability are described under conditions of 1) overuse: imposed electrical stimulation, natural exercise and functional overload; 2) reinnervation of denervated muscles; and 3) underusage: conditions of restricted use after spinal cord injury, weightlessness, immobilization and drug-induced neuromuscular blockade. These conditions demonstrate the remarkable plasticity of muscle fibers with obvious implications in health and disease. They also identify that the amount of neuromuscular activity and loading of muscle contractions are major factors determining susceptibility to fatigue and muscle strength, respectively

Gould N., Donnermeyer D., Gammon G.G., Pope M., and Ashikaga T. (1983) Transcutaneous muscle stimulation to retard disuse atrophy after open meniscectomy. Clin. Orthop. 190-197.
Abstract: Immobilization of an extremity inevitably results in disuse muscle atrophy. The effectiveness of transcutaneous muscle stimulation by a portable device in preventing atrophy has been determined. Ten patients treated by open meniscectomy and given the usual isometric training were matched with ten patients in whom electrostimulation, consisting of a strong, tetanizing, five-second sustained muscular contraction about 400 times/day, was used for two weeks. Muscular strength and leg circumference were measured before surgery and four weeks after surgery. The electrically stimulated group had a significantly smaller loss of muscle volume and muscle strength, were able to walk earlier without crutches, had a greater range of knee motion, had much less postoperative knee swelling, and used significantly less pain medication. Transcutaneous electrical stimulation may prevent muscle atrophy due to immobilization, thereby shortening rehabilitation time

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

Hainaut K. and Duchateau J. (1992) Neuromuscular electrical stimulation and voluntary exercise. Sports Med. 14, 100-113.
Abstract: Neuromuscular electrical stimulation (NMES) has been in practice since the eighteenth century for the treatment of paralysed patients and the prevention and/or restoration of muscle function after injuries, before patients are capable of voluntary exercise training. More recently NMES has been used as a modality of strengthening in healthy subjects and highly trained athletes, but it is not clear whether NMES is a substitute for, or a complement to, voluntary exercise training. Moreover the discussion of the mechanisms which underly the specific effects of NMES appears rather complex at least in part because of the disparity in training protocols, electrical stimulation regimens and testing procedures that are used in the various studies. It appears from this review of the literature that in physical therapy, NMES effectively retards muscle wasting during denervation or immobilisation and optimises recovery of muscle strength during rehabilitation. It is also effective in athletes with injured, painful limbs, since NMES contributes to a shortened rehabilitation time and aids a safe return to competition. In healthy muscles, NMES appears to be a complement to voluntary training because it specifically induces the activity of large motor units which are more difficult to activate during voluntary contraction. However, there is a consensus that the force increases induced by NMES are similar to, but not greater than, those induced by voluntary training. The rationale for the complementarity between NMES and voluntary exercise is that in voluntary contractions motor units are recruited in order, from smaller fatigue resistant (type I) units to larger quickly fatiguable (type II) units, whereas in NMES the sequence appears to be reversed. As a training modality NMES is, in nonextreme situations such as muscle denervation, not a substitute for, but a complement of, voluntary exercise of disused and healthy muscles

Hamnegard C.H., Wragg S.D., Mills G.H., Kyroussis D., Polkey M.I., Bake B., Moxham J., and Green M. (1996) Clinical assessment of diaphragm strength by cervical magnetic stimulation of the phrenic nerves. Thorax 51, 1239-1242.
Abstract: BACKGROUND: Accurate assessment of diaphragm strength can be difficult. Transdiaphragmatic pressure (PDI) measurements during volitional manoeuvres are useful but it may be difficult to ensure maximum patient effort. Magnetic stimulation of the phrenic nerves is easy to perform and the results are reproducible in normal subjects. The purpose of the present study was to evaluate the usefulness of magnetic stimulation of the phrenic nerves in the assessment of diaphragm weakness in patients. METHODS: Sixty-six patients referred for assessment of respiratory muscle strength and 23 normal subjects were studied.

Twitch PDI (TwPDI) following magnetic stimulation of the phrenic nerves and sniffPDI were obtained in all individuals. TWPDI following bilateral electrical stimulation of the phrenic nerves was also obtained in eight patients. RESULTS: Mean (SD) TwPdi for the normal subjects was 31 (6) cm H2O and 18 (11) cm H2O for the patients. TwPDI and sniffPDI were correlated (r = 0.77). Seven of the 37 patients (19%) with a reduced sniffPDI had a TwPDI within the normal range whereas two of the 32 patients (6%) with a reduced TwPDI had a normal sniffPDI. TwPDI was similar with magnetic and electrical stimulation. CONCLUSIONS: TwPDI following magnetic stimulation of the phrenic nerves is a clinically useful measurement when assessing diaphragm weakness

Harridge S.D., Magnusson G., and Gordon A. (1996) Skeletal muscle contractile characteristics and fatigue resistance in patients with chronic heart failure. Eur. Heart J. 17, 896-901.
Abstract: Whole muscle contractile characteristics and fatigue resistance were studied in male patients with chronic heart failure (n = 6) and in healthy control subjects (n = 6). Maximum voluntary isometric strength in the major muscle groups of leg (plantar flexors and knee extensors) and arm (elbow extensors and elbow flexors), was found to be similar for both groups of subjects. However, a faster isometric twitch time course was observed in the plantar flexor and knee extensor muscles of heart failure chronic patients. The poor resistance to fatigue in the knee extensors of chronic heart failure patients was confirmed in the present study, but using twitch interpolation this was shown not to be due to poor activation. The plantar flexors of chronic heart failure patients also showed a tendency to be less resistant to fatigue, even when the muscle was activated by direct electrical stimulation. The present study shows that independent of muscle strength, patients with chronic heart failure may possess muscles that are faster to contract and less resistant to fatigue. However, it seems this increased fatigability is not due to poor muscle activation

Harris M.L., Luo Y.M., Watson A.C., Rafferty G.F., Polkey M.I., Green M., and Moxham J. (2000) Adductor pollicis twitch tension assessed by magnetic stimulation of the ulnar nerve. Am. J. Respir. Crit Care Med. 162, 240-245.
Abstract: Many critically ill patients develop significant skeletal muscle weakness in the Intensive Care Unit (ICU), which ultimately may cause difficulties in weaning from mechanical ventilation and a protracted, expensive ICU stay. Reliable monitoring of muscle strength in this environment is difficult. The purpose of this study was to develop a reproducible, nonvolitional method of measuring adductor pollicis (AP) muscle function by magnetic stimulation of the ulnar nerve (MSUN) that could be applied to patients in the ICU and operating theater (OT). Fifty subjects (32 healthy control subjects [12 of whom were elderly], 12 ICU patients with critical illness [mean APACHE II score 20], and six otherwise healthy patients requiring minor surgery in the OT) received MSUN. In 12 of the normal subjects electrical stimulation of the ulnar nerve (ESUN) and MSUN were compared and AP twitch tension (Tw AP) and surface electromyogram (EMG) were measured. Close agreement was found between supramaximal Tw AP (median [95% CI] for MSUN 6.3 N [5-7.2 N] and ESUN 6.9 N [5.2-7.8 N] [p = NS]). Median (95% CI) values with MSUN for the 20 young and 12 elderly control subjects were 6.9 N (5. 3- 7.4 N) and 7.1 N (4.4-9.8 N). Median (95% CI) Tw AP for the ICU group was 4.2 (2.2-6.7 N) and for the OT group was 5.8 (4-9.1 N). Tw AP was significantly reduced in ICU patients compared with age-matched controls (p = 0.01). MSUN can be used to measure neuromuscular function in both the laboratory and clinical settings including the ICU

Hesse S., Malezic M., Schaffrin A., and Mauritz K.H. (1995) Restoration of gait by combined treadmill training and multichannel electrical stimulation in non-ambulatory hemiparetic patients. Scand. J. Rehabil. Med. 27, 199-204.
Abstract: Functional electrical stimulation and treadmill training with partial body weight support through suspension by a parachute harness were combined for gait restoration in 11 chronic non-ambulatory hemiparetic patients. Individually adjusted multichannel stimulation of the trunk and of upper and lower limb muscles, as well as a motor driven treadmill, induced functional gait within 3 to 6 weeks. The improvement of gait ability was assessed by the Functional Ambulation Category test. Other motor functions were rated by the Rivermead Motor Score. The leg muscle strength, stride length, cadence, gait velocity and gait pattern were recorded. In seven of the patients, we did a single case research A-B-A study that showed that this combined approach had advantages, in regard to gait restoration and walking velocity ($p < 0.05$) as compared with our common physiotherapeutic programme

Jacobsen S., Wildschiodtz G., and Danneskiold-Samsoe B. (1991) Isokinetic and isometric muscle strength combined with transcutaneous electrical muscle stimulation in primary fibromyalgia syndrome. J. Rheumatol. 18, 1390-1393.
Abstract: Twenty women with primary fibromyalgia syndrome and 20 age matched healthy women were investigated. The subjects performed maximum voluntary isokinetic contractions of the right quadriceps in an isokinetic dynamometer. Maximum voluntary isometric contractions of the right quadriceps were performed with superimposed transcutaneous electrical stimulation. The examination protocol was repeated after 1 h of resting. Isokinetic and isometric muscle strength was found to be, respectively, 45% ($p = 0.0001$) and 44% ($p = 0.0001$) lower in the patient group compared to the healthy subjects. The frequency of superimposed twitches was 65% in the patient group and 15% in the control group ($p = 0.003$). Patients with primary fibromyalgia have a lower maximum voluntary muscle strength than expected. The increased presence of superimposed electrically elicited twitches during maximum voluntary contraction indicates submaximal force application in primary fibromyalgia syndrome

Johannsson G., Grimby G., Sunnerhagen K.S., and Bengtsson B.A. (1997) Two years of growth hormone (GH) treatment increase isometric and isokinetic muscle strength in GH-deficient adults. J. Clin. Endocrinol. Metab 82, 2877-2884.
Abstract: GH deficiency in adults is associated with reduced muscle mass and muscle strength. The objective of this trial was to follow the effect of 2 yr of GH treatment in GH-deficient adults on muscle performance in relation to a reference population. Knee extensor and flexor strengths for isometric and isokinetic concentric muscle strength were measured using a Kin-Com dynamometer. Hand-grip strength was measured in both hands. The fatigue index was calculated as the percent reduction in peak torque at 50 repeated isokinetic knee extensions. Superimposed, single twitch electrical stimulation was performed. The GH-deficient subjects had lower isometric knee extensor, knee flexor, and hand-grip strength than the reference population. Two years of GH treatment increased and normalized the mean isometric knee extensor and flexor strengths. The concentric knee flexor and extensor strength at an angular velocity of pi rad/s increased, as did the concentric knee flexor strength at an angular velocity of pi/3 rad/s. The increase in muscle strength was more marked in younger patients and in patients with lower initial muscle strength than predicted. Quadriceps endurance decreased, whereas the effect of superimposing single twitches on isometric contraction and hand-grip

strength was unaffected by the GH treatment. Two years of GH therapy in GH-deficient adults increased and normalized isokinetic and isometric muscle strength studied in proximal muscle groups. Hand-grip strength and the degree of lack of maximal motor unit activation on voluntary isometric knee extensor force did not change. The dynamic local muscle fatigue index decreased

Kahanovitz N., Nordin M., Verderame R., Yabut S., Parnianpour M., Viola K., and Mulvihill M. (1987) Normal trunk muscle strength and endurance in women and the effect of exercises and electrical stimulation. Part 2: Comparative analysis of electrical stimulation and exercises to increase trunk muscle strength and endurance. Spine 12, 112-118.
Abstract: Several studies have shown positive correlations between muscle strength, flexibility, and the frequency of low-back pain. Weak trunk musculature and decreased endurance have thereby come to be identified as significant risk factors in the development of occupational back problems. Because it is widely accepted that exercise plays an important role in the conservative treatment and prevention of low-back pain, the goals of most rehabilitative programs involves improving the strength and endurance of the low-back pain patient. Whereas electrical stimulation has been shown to increase the muscle strength of the lower extremities, this effect has not been demonstrated for the trunk muscles. Part 2 is a prospective controlled study designed to document and to compare objectively the effects of electrical stimulation and exercise on trunk muscle strength. A total of 117 healthy women were divided randomly into four groups. Two groups received electrical stimulation with different electrical parameters, one group received exercises, and one group acted as a control group. The results showed that low-frequency electrical stimulation and exercises significantly (P less than .05) increased isokinetic back-muscle strength compared to the control and medium-high-frequency electrical stimulation groups. Both types of electrical stimulation, however, significantly increased (P less than .05) the endurance in the back muscles compared with the control and the exercise groups. This study showed that electrical stimulation may be a valuable treatment in the early care of low-back pain patients in maintaining and increasing strength and endurance of back muscles when a more active exercise program is too painful to perform

Kirdi N., Yakut E., and Meric A. (1998) Peroneal nerve injuries as a complication of injection. Turk. J. Pediatr. 40, 405-411.
Abstract: Ten children (8 males, 2 females) diagnosed with peroneal nerve injury as a complication of injection were included in this study. The age of the children ranged between four to seven years (mean 6.5 +/- 1.25 years). Physiotherapy and rehabilitation protocol included superficial heat, neuromuscular electrical stimulation (either galvanic or faradic current according to the response elicited), electromyographic biofeedback, exercises (passive, active-assistive and active), and orthotic support. Before treatment, foot-drop and steppage gait were observed in all the patients; both were remedied. The post-treatment muscle strength and electrodiagnostic test results showed statistically significant improvement when compared with pretreatment values ($p < 0.05$). We believe that our relatively favorable results in this study, manifested as shorter recovery time with no residual deficits, may be related to early intervention with an extensive physiotherapy program

Kuo A.D. and Zajac F.E. (1993) A biomechanical analysis of muscle strength as a limiting factor in standing posture. J. Biomech. 26 Suppl 1, 137-150.
Abstract: We developed a method for studying muscular coordination and strength in multijoint movements and have applied it to standing posture. The method is based on a musculoskeletal model of the human lower extremity in the sagittal plane and a technique to visualize, geometrically, how constraints internal and external to the body affect movement. We developed an algorithm to calculate the set of all feasible accelerations (i.e., the 'feasible acceleration set', or FAS) that muscles can induce. For the ankle, knee, and hip joints in the sagittal plane, this set is a polyhedron in three dimensions. Using the volume of the FAS as an indicator of overall mobility, we found that strengthening muscles on the posterior side (as opposed to the anterior) of the body would cause greater increases in mobility. Employing the experimental observations of others, we also found that acceleration constraints greatly reduce the range of feasible accelerations. We then defined a set of four basic acceleration vectors which, when used in various combinations, can produce the repertoire of postural movements. We used linear programming to find the maximum magnitudes of these vectors, and the sensitivity of these magnitudes to muscle strength, thereby delineating those muscles which, if strengthened, would cause the greatest increase in the body's ability to generate the basic acceleration vectors. For our particular model, those muscle groups were found to be hamstrings, tibialis anterior, rectus femoris, and gastrocnemius. These muscle groups would be of great importance in cases involving severely reduced muscle strength. This methodology may therefore be useful for purposes such as design of functional electrical stimulation controllers or exercises for persons at risk for falling

Lake D.A. (1992) Neuromuscular electrical stimulation. An overview and its application in the treatment of sports injuries. Sports Med. 13, 320-336.
Abstract: In sports medicine, neuromuscular electrical stimulation (NMES) has been used for muscle strengthening, maintenance of muscle mass and strength during prolonged periods of immobilisation, selective muscle retraining, and the control of oedema. A wide variety of stimulators, including the burst-modulated alternating current ('Russian stimulator'), twin-spiked monophasic pulsed current and biphasic pulsed current stimulators, have been used to produce these effects. Several investigators have reported increased isometric muscle strength in both NMES-stimulated and exercise-trained healthy, young adults when compared to unexercised controls, and also no significant differences between the NMES and voluntary exercise groups. It appears that when NMES and voluntary exercise are combined there is no significant difference in muscle strength after training when compared to either NMES or voluntary exercise alone. There is also evidence that NMES can improve functional performance in a variety of strength tasks. Two mechanisms have been suggested to explain the training effects seen with NMES. The first mechanism proposes that augmentation of muscle strength with NMES occurs in a similar manner to augmentation of muscle strength with voluntary exercise. This mechanism would require NMES strengthening protocols to follow standard strengthening protocols which call for a low number of repetitions with high external loads and a high intensity of muscle contraction. The second mechanism proposes that the muscle strengthening seen following NMES training results from a reversal of voluntary recruitment order with a selective augmentation of type II muscle fibres. Because type II fibres have a higher specific force than type I fibres, selective augmentation of type II muscle fibres will increase the overall strength of the muscle. The use of neuromuscular electrical stimulation to prevent muscle

atrophy associated with prolonged knee immobilisation following ligament reconstruction surgery or injury has been extensively studied. NMES has been shown to be effective in preventing the decreases in muscle strength, muscle mass and the oxidative capacity of thigh muscles following knee immobilisation. In all but one of the studies, NMES was shown to be superior in preventing the atrophic changes of knee immobilisation when compared to no exercise, isometric exercise of the quadriceps femoris muscle group, isometric co-contraction of both the hamstrings and quadriceps femoris muscle groups, and combined NMES- isometric exercise. It has also been reported that NMES applied to the thigh musculature during knee immobilisation improves the performance on functional tasks.(ABSTRACT TRUNCATED AT 400 WORDS)

Lindehammar H. and Backman E. (1995) Muscle function in juvenile chronic arthritis. J. Rheumatol. 22, 1159-1165.
Abstract: OBJECTIVE. Muscle strength and thickness were studied in children with juvenile chronic arthritis (JCA) to evaluate their muscle function. METHODS. We studied voluntary isometric, isokinetic, and nonvoluntary isometric muscle strength, as well as muscle thickness, in 20 children with JCA. Thickness of the quadriceps muscle was measured by ultrasound. Results were compared with reference values for healthy children and a matched control group. RESULTS. Isometric muscle strength in knee extensors, elbow flexors, and wrist dorsiflexors was reduced in children with JCA. In muscles near an inflamed joint, the strength was 45-65% of expected value. In muscles without adjacent arthritis, the strength was slightly decreased (80-90% of expected value). Isometric and isokinetic strength in ankle dorsiflexors was reduced only in children with ankle arthritis. Nonvoluntary muscle strength in thumb adductors during electrical stimulation of the ulnar nerve was reduced in children with arthritis in the hand. Thickness of the quadriceps muscle was reduced both in children with and without knee arthritis (75 and 90% of expected). CONCLUSION. Children with JCA have reduced muscle strength and thickness, which is most pronounced in muscles near an inflamed joint

Lindh M.H., Johansson L.G., Hedberg M., and Grimby G.L. (1994) Studies on maximal voluntary muscle contraction in patients with fibromyalgia. Arch. Phys. Med. Rehabil. 75, 1217-1222.
Abstract: In view of clinical experience of a low-force output in testing situations in patients with fibromyalgia syndrome (FS), this study evaluated the possibility of reaching a higher muscular performance by use of superimposed electrical stimulation: the tests mainly involved knee-extension in a Kin Com dynamometer. Twenty-five patients fulfilling the criteria of FS were compared with 22 healthy subjects. The patients showed a markedly reduced maximal voluntary contraction, but superimposed electrical stimulation revealed submaximal values. The electromyographic activity during stool climbing exceeded that recorded during maximum voluntary contraction during the dynamometric test. The cause of the reduced voluntary maximal performance is discussed. An impaired control mechanism at a supraspinal level is suggested. This has to be considered when measuring muscle strength in FS patients. Tests related to functional activities are recommended as measures of muscular performance in this patient group

Mills G.H., Kyroussis D., Hamnegard C.H., Wragg S., Polkey M.I., Moxham J., and Green M. (1997) Cervical magnetic stimulation of the phrenic nerves in bilateral diaphragm paralysis. Am. J. Respir. Crit Care Med. 155, 1565-1569.

Abstract: Cervical magnetic stimulation (CMS) produces a greater twitch transdiaphragmatic pressure (TwPdi) than electrical stimulation. This may be because CMS produces rib cage muscle activation, thus producing an inspiratory action independent of the diaphragm. Alternatively, CMS could merely stiffen the rib cage, allowing the diaphragm to act efficiently, by contracting against a stable rib cage. To examine these two hypotheses we studied five patients with isolated bilateral diaphragm paralysis using CMS and bilateral electrical phrenic stimulation (BES). TwPdi, twitch esophageal pressure (TwPes), and twitch gastric pressure (TwPgas) were measured. We also assessed maximal sniff esophageal and transdiaphragmatic pressures (SnPes) (SnPdi), maximal inspiratory and expiratory mouth pressures (MIP) (MEP), and fall in VC on moving from an upright to a supine position. Respiratory muscle strength tests were consistent with bilateral diaphragm paralysis, and the MEPs confirmed normal expiratory muscle function. The patients were able to generate a mean SnPes of -30 cm H2O, mainly because of inspiratory activity of rib cage and neck muscles. However, TwPdi and TwPes during both CMS and BES were close to zero. We conclude that in our patients with diaphragm paralysis caused by neuralgic amyotrophy, CMS stiffens the rib cage but does not have an inspiratory action independent of the diaphragm

Mohr T., Carlson B., Sulentic C., and Landry R. (1985) Comparison of isometric exercise and high volt galvanic stimulation on quadriceps femoris muscle strength. Phys. Ther. 65, 606-612.
Abstract: The purpose of this study was to compare the effectiveness of both high volt galvanic current (HVG) and isometric exercise to strengthen the quadriceps femoris muscles in 17 healthy subjects. The subjects were divided into three groups. The Control Group (n = 6) received no exercise or stimulation. The Isometric Exercise Group (n = 5) performed 15 sessions of maximum isometric contractions, and the Electrical Stimulation Group (n = 6) engaged in 15 sessions of electrically stimulated isometric contractions. The Isometric Exercise Group was found to have an increase in strength significantly greater (p less than .05) than either the Control or Electrical Stimulation Group. No increase in strength was observed in either the Control or Electrical Stimulation Group. This study indicates that HVG stimulation is not as effective as isometric exercise in increasing strength in muscle

Nordin M., Kahanovitz N., Verderame R., Parnianpour M., Yabut S., Viola K., Greenidge N., and Mulvihill M. (1987) Normal trunk muscle strength and endurance in women and the effect of exercises and electrical stimulation. Part 1: Normal endurance and trunk muscle strength in 101 women. Spine 12, 105-111.
Abstract: The lack of trunk muscle strength and endurance has frequently been cited as a suspected factor in the etiology of low-back pain. Several investigators have suggested that asymptomatic patients have stronger trunk muscles than patients with low-back pain. People who are physically fit appear to have a decreased incidence of low-back pain. Increased trunk muscle endurance also have been observed to decrease the incidence of low-back pain. The objective evaluation of the strength and endurance of trunk musculature may, therefore, be significant. Part 1 of this study was designed to develop a reproducible strength-endurance screening procedure and to establish normal isometric-isokinetic trunk muscle strength and endurance parameters for women. This study showed that isometric trunk flexion varied from 19-109 Nm and trunk extension from 38-168 Nm. Peak values for isokinetic trunk flexion at two speeds (30 degrees per second and 60 degrees per second) varied from 17-191 Nm and isokinetic trunk extension from 14-208 Nm. The

average endurance time for trunk extensors tested with the Sorensen test was 196 seconds

Pantoja J.G., Andrade F.H., Stoki D.S., Frost A.E., Eschenbacher W.L., and Reid M.B. (1999) Respiratory and limb muscle function in lung allograft recipients. Am. J. Respir. Crit Care Med. 160, 1205-1211.
Abstract: Lung transplantation recipients have reduced exercise capacity despite normal resting pulmonary and hemodynamic function. The limiting factor may be contractile dysfunction of skeletal muscle. To test this postulate, we measured limb and respiratory muscle function in nine clinically stable lung allograft recipients (six men and three women, aged 30 to 65 yr, at 5 to 102 mo after transplantation) with reduced exercise capacity. Respiratory muscle strength was tested by measuring maximal inspiratory and expiratory pressure (MIP and MEP, respectively). Ankle dorsiflexor muscle strength was measured during maximal voluntary contraction (MVC). In a subset of six recipients, we also measured contractile properties and fatigue characteristics of the tibialis anterior muscle, using electrical stimulation of the motor point. Data were compared with values from age- and sex-matched control subjects. MIP values of transplant recipients did not differ from control values; however, MEP was blunted by 30% relative to control ($p < 0.05$), and MVC was decreased by 39% (p Y 0.05). The force-frequency relationships and fatigue characteristics of the tibialis anterior were not different between the patient and control groups. We conclude that stable lung allograft recipients experience expiratory and lower limb weakness that may contribute to exercise intolerance

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

Pichard C., Kyle U., Chevrolet J.C., Jolliet P., Slosman D., Mensi N., Temler E., and Ricou B. (1996) Lack of effects of recombinant growth hormone on muscle function in patients requiring prolonged mechanical ventilation: a prospective, randomized, controlled study. Crit Care Med. 24, 403-413.
Abstract: OBJECTIVE: To evaluate the benefit of recombinant human growth hormone administration on muscle strength and duration of weaning in critically ill

patients undergoing prolonged mechanical ventilation. DESIGN: Prospective, randomized, controlled, single-blind study. SETTING: Intensive care unit. Patients: Twenty patients requiring > or = 7 days of mechanical ventilation for acute respiratory failure. INTERVENTION: Random assignment to receive either 0.43 IU (approximately 0.14 mg) recombinant growth hormone/kg body weight/day (treated group), or saline (nontreated group) for 12 days. MEASUREMENTS AND MAIN RESULTS: Nutritional support was guided by indirect calorimetry. Cumulative nitrogen balance was positive throughout the study period in the treated group 17.3 (44.9 +/- 17.3[SEM] g/12 days) vs. the nontreated group (-65.8 +/- 11.8 g/12 days) (p<.0001). Despite similar initial plasma concentrations, recombinant growth hormone supplementation resulted in marked increases in growth hormone, insulin like growth factor-1, and insulin concentrations (p<.05, .02, and .0001, respectively, vs. nontreated group). Body impedance determined net fat- free mass increased in the treated group (0.8 +/- 0.6 kg) vs. the nontreated group (-1.1 +/- O.5 kg) (p<.03). Initial peripheral muscle function, assessed by computer-controlled electrical stimulation of the adductor pollicis, was similarly lower in treated and nontreated groups than sex and age-matched normal controls, and decreased further during the study period. Arterial blood gases, cumulative total mechanical ventilation time, and number of hrs/day of mechanical ventilation during weaning were similar in both patient groups. Only three of the ten patients in each group were weaned from mechanical ventilation by day 12. CONCLUSIONS: Daily administration of recombinant growth hormone in mechanically ventilated patients with acute respiratory failure promotes a marked nitrogen retention. However, this reaction is accompanied neither by an improvement in muscle strength nor by a shorter duration of ventilatory supports

Pournezam M., Andrews B.J., Baxendale R.H., Phillips G.F., and Paul J.P. (1988) Reduction of muscle fatigue in man by cyclical stimulation. J. Biomed. Eng 10, 196-200.
Abstract: In order to develop a control system for electrical stimulation of paralysed muscle and improve muscle resistance to fatigue, it is useful to investigate the possibilities of simulating the control systems of the normal body. One way is the periodic shifting of stimulation from one muscle to another. This technique is called sequential stimulation and allows sufficient rest time for each muscle to reduce fatigue and consequently prolong muscle strength. It can also be seen to improve the muscle recovery time. In the following study, the muscles rectus femoris, vastus lateralis and vastus medialis were used to keep the knee locked and extended during stimulation. Several experiments were carried out using a three-channel computer controlled stimulator. The results for three-phase sequential stimulation (33% duty cycle per muscle) were most effective and significantly improved the muscle fatigue characteristics

Quittan M., Sochor A., Wiesinger G.F., Kollmitzer J., Sturm B., Pacher R., and Mayr W. (1999) Strength improvement of knee extensor muscles in patients with chronic heart failure by neuromuscular electrical stimulation. Artif. Organs 23, 432-435.
Abstract: Patients with severe chronic heart failure (CHF) suffer from marked weakness of skeletal muscles. Neuromuscular electrical stimulation (NMES) proved to be an alternative to active strength training. The objective of this study was to test the feasibility and effectiveness of NMES in patients with chronic heart failure. Seven patients (56.0 +/- 5.0 years, CHF for 20 +/- 4 months, left ventricular ejection fraction 20.1 +/- 10.0%) finished an 8 week course of NMES of the knee extensor muscles.

The stimulator delivered biphasic, symmetric, constant voltage impulses of 0.7 ms pulse width with a frequency of 50 Hz, 2 s on and 6 s off. No adverse effects occurred. After the stimulation period, the isokinetic peak torque of the knee extensor muscles increased by 13% from 101.0 +/- 8.7 Nm to 113.5 +/- 7.2 Nm (p = 0.004). The maximal isometric strength increased by 20% from 294.3 +/- 19.6 N to 354.14 +/- 15.7 N (p = 0.04). This increased muscle strength could be maintained in a 20 min fatigue test indicating decreased muscle fatigue. These results demonstrate that NMES of skeletal muscles in patients with severe chronic heart failure is a promising method for strength training in this group of patients

Quittan M., Wiesinger G.F., Sturm B., Puig S., Mayr W., Sochor A., Paternostro T., Resch K.L., Pacher R., and Fialka-Moser V. (2001) Improvement of thigh muscles by neuromuscular electrical stimulation in patients with refractory heart failure: a single-blind, randomized, controlled trial. Am. J. Phys. Med. Rehabil. 80, 206-214. Abstract: OBJECTIVE: To determine the impact of an 8-wk neuromuscular stimulation program of thigh muscles on strength and cross-sectional area in patients with refractory heart failure listed for transplantation. DESIGN: Forty-two patients with a stable disease course were assigned randomly to a stimulation group (SG) or a control group (CG). The stimulation protocol consisted of biphasic symmetric impulses with a frequency of 50 Hz and an on/off regime of 2/6 sec. RESULTS: Primary outcome measures were isometric and isokinetic thigh muscle strength and muscle cross-sectional area. Our results showed an increase of muscle strength by mean 22.7 for knee extensor and by 35.4 for knee flexor muscles. The CG remained unchanged or decreased by -8.4 in extensor strength. Cross-sectional area increased in the SG by 15.5 and in the CG by 1.7. CONCLUSIONS: Activities of daily living as well as quality of life increased in the SG but not in the CG. Subscales of the SF-36 increased significantly in the SG, especially concerning physical functioning by +7.5 (1.3-30.0), emotional role by +33.3 (0-66.6), and social functioning by +18.8 (0-46.9), all P a 0.05. Neither a change nor a decrease was observed in the CG. Neuromuscular electrical stimulation of thigh muscles in patients with refractory heart failure is effective in increasing muscle strength and bulk and positively affects the perception of quality of life and activities of daily living

Rabischong E. and Ohanna F. (1992) Effects of functional electrical stimulation (FES) on evoked muscular output in paraplegic quadriceps muscle. Paraplegia 30, 467-473. Abstract: In order to assess the effects of FES on muscle output, chronic electrical stimulation of the quadriceps muscle was applied for half an hour twice a day for 2 months, in 10 thoracic level traumatic paraplegic patients. Results concerning torque (at 6 different muscle lengths) and fatigue were measured using a strain gauge transducer in isometric condition, and compared with the findings in 15 paraplegic patients who had not received electrical stimulation, and with 10 able bodied subjects with normal motor functions. With training, muscle strength was very significantly improved whilst fatigue resistance remained at a low level. The peak torque was not found to be of the same muscle length when comparing paraplegics and control subjects; it seemed to demonstrate that length-tension relationship of the muscular actuator was changing when it was electrically activated. Moreover, the force recorded in paraplegics remained markedly lower than in able bodied people

Richardson J.H. and Allen R.B. (1983) Dietary supplementation with vitamin C delays the onset of fatigue in isolated striated muscle of rats. Can. J. Appl. Sport Sci. 8, 140-142.

Abstract: The purpose of this study was to assay the effect of prolonged vitamin C supplementation on contraction time and strength in the gastrocnemius muscle of the rat. Fifteen male Sprague-Dawley rats were given 30 mg of vitamin C orally per day for thirty days, while an additional fifteen animals served as controls. Contraction of the isolated gastrocnemius muscle was induced by electrical stimulation, and strength and time to fatigue was measured. Results indicate that the supplementation of vitamin C prolongs contraction time by 19% thus delaying fatigue but had no affect on muscle strength

Royall D., Jeejeebhoy K.N., O'Connor B., Taylor B.R., Langer B., and McLeod R.S. (1996) Nutritional status and function in patients following Whipple procedure compared with controls. J. Am. Coll. Nutr. 15, 73-78.
Abstract: OBJECTIVE: Despite the potential for nutritional deficits in patients undergoing pancreaticoduodenectomy or Whipple procedure, long-term assessment of nutritional status has largely been ignored. This study assessed nutritional status of 24 Whipple patients compared with matched post-cholecystectomy controls. METHODS: Clinical assessment was by subjective global assessment, body composition was assessed by bioelectric impedance analysis and functional assessment was by respiratory muscle strength and skeletal muscle function performed by electrical stimulation of the ulnar nerve of the wrist and hand-grip dynamometry. RESULTS: Whipple patients studied 4.6+/-0.7 years since surgery and controls (4.8+/-0.7 years since surgery) were all judged clinically to be in a good nutritional state. Compared with controls, Whipple patients had significantly lower body weight (Whipple: 72.5+/- 2.8 kg, control: 83.9+/-3.3 kg, $p<0.05$) however, the mean body weight of both Whipple and controls was above ideal weight (Whipple: 113.3+/- 4.3%, control: 122.3+/-3.7% p = NS). No significant differences in functional performance were observed between groups. Energy intake of Whipple and controls was also comparable. In the Whipple group, neither the extent of gastric resection or the pathological diagnosis had an effect on the nutritional parameters studied. CONCLUSIONS: Long-term follow-up of patients having undergone Whipple procedure failed to reveal the presence of any nutritional or functional deficits suggesting that a full nutritional recovery is possible after this surgery

Rutherford O.M., Jones D.A., and Round J.M. (1990) Long-lasting unilateral muscle wasting and weakness following injury and immobilisation. Scand. J. Rehabil. Med. 22, 33-37.
Abstract: Quadriceps strength and size was measured in a small group of subjects (n = 7) 1 to 5 years after full mobilisation following some form of unilateral lower limb trauma. The mean maximum voluntary isometric force (MVC) was significantly lower for the injured (I) compared to the uninjured (UI) leg (369 N +/- 139 vs. 535 N +/- 131, p less than 0.01). Electrical stimulation superimposed on the voluntary contractions demonstrated that all subjects were able to maximally activate the quadriceps of both legs. Mean quadriceps cross-sectional area (CSA) was significantly lower in the I (64 cm2 +/- 12.8) compared to the UI leg (80 +/- 12.8, p less than 0.01). One subject with marked unilateral weakness and wasting took part in a 3-month strength training study for the injured leg. After training the I/UI ratio had been restored to nearly 100% (94% MVC; 88% CSA). These results would suggest that longer and more intensive physiotherapy is required in the immediate post-injury period to restore muscle strength and size to severely atrophied muscle

Sand P.K., Richardson D.A., Staskin D.R., Swift S.E., Appell R.A., Whitmore K.E., and Ostergard D.R. (1995) Pelvic floor electrical stimulation in the treatment of genuine stress incontinence: a multicenter, placebo-controlled trial. Am. J. Obstet. Gynecol. 173, 72-79.
Abstract: OBJECTIVE: Our purpose was to determine the efficacy of transvaginal electrical stimulation in treating genuine stress incontinence. STUDY DESIGN: This was a multicenter, prospective, randomized, double-blind, placebo-controlled 15-week trial comparing the use of an active pelvic floor stimulator with a sham device. Thirty-five women used an active unit and 17 control subjects used sham devices. Weekly and daily voiding diaries were recorded throughout the trial. Urodynamic testing, including pad test and subtracted cystometry, was done before and at the end of device use. Pelvic muscle strength was measured at baseline and at the end of the trial. Patients scored their symptoms on visual analog scales and completed quality-of-life questionnaires before and after therapy. RESULTS: Significant improvements from baseline were found in patients using active devices but not in controls. Comparisons of changes from baseline between active-device and control patients showed that active-device patients had significantly greater improvement in weekly ($p = 0.009$) and daily ($p = 0.04$) leakage episodes, pad testing ($p = 0.005$), and vaginal muscle strength ($p = 0.02$) when compared with control subjects. Significantly greater improvement was also found for both visual analog scores of urinary incontinence ($p = 0.007$) and stress incontinence ($p = 0.02$), as well as for subjective reporting of frequency of urine loss ($p = 0.002$), and urine loss with sneezing, coughing, or laughing ($p = 0.02$), when compared with controls. Pad testing showed that stress incontinence was improved by at least 50% in 62% of patients using an active device compared with only 19% of patients using sham devices ($p = 0.01$). Voiding diaries showed at least 50% improvement in 48% of active-device patients compared with 13% of women using the sham device ($p = 0.02$). No irreversible adverse effects were noted in either group. CONCLUSIONS: Transvaginal pelvic floor electrical stimulation was found to be a safe and effective therapy for genuine stress incontinence

Seeger B.R., Law D., Creswell J.E., Stern L.M., and Potter G. (1989) Functional electrical stimulation for upper limb strengthening in traumatic quadriplegia. Arch. Phys. Med. Rehabil. 70, 663-667.
Abstract: The hypothesis of this study was that the functional electrical stimulation (FES)-assisted exercise of partially paralyzed arm muscles would result in significantly greater muscle strength in the arms of spinal cord injured quadriplegics than equal periods of conventional isotonic exercise. Single muscles were studied in seven subjects in a crossover design consisting of equal periods of FES-assisted exercise and conventional exercise. It was concluded that for these subjects using this exercise regime, neither FES-assisted exercise nor conventional exercise produced improvements in maximum voluntary force that were either statistically or functionally significant. The results, although disappointing, have helped these subjects to be more realistic about the potential therapeutic benefits of FES

Stein R.B. (1999) Functional electrical stimulation after spinal cord injury. J. Neurotrauma 16, 713-717.
Abstract: This article reviews work mainly from my own laboratory on the effects of electrical stimulation for therapy and function following spinal cord injury. One to two hours per day of intermittent stimulation can increase muscle strength and endurance and also reverse some of the osteoporosis in bones that are stressed by

the stimulation. Stimulation during walking can also be used to improve speed and other parameters of the gait. Surface stimulation systems with 1-4 channels of stimulation were used in a multicenter study. Initial increases of almost 20% in walking speed were seen and overall increases of nearly 50% in subjects who continued to receive stimulation for a year on average. Some changes were due to improved strength and coordination with stimulation and additional walking, but a specific effect of stimulation persisted throughout the trial. Improved devices will soon be available commercially that were developed on the basis of feedback from users

Stokes M.J., Edwards R.H., and Cooper R.G. (1989) Effect of low frequency fatigue on human muscle strength and fatigability during subsequent stimulated activity. Eur. J. Appl. Physiol Occup. Physiol 59, 278-283.
Abstract: Fatiguing contractions of the adductor pollicis muscle were produced by intermittent supramaximal stimulation of the ulnar nerve in a set frequency pattern, in six normal subjects. At the end of an initial fatiguing contraction series, low frequency fatigue (LFF) had been induced and persisted at 15 min of recovery. Stimulated fatiguing activity was then repeated in an identical fashion to the initial series. At high frequencies, declines in force were similar for both series. At low frequencies, declines in force were greater during the second series despite similar changes in compound muscle action potential amplitude. This confirmation that LFF persists during subsequent stimulated activity, and reduces low but not high frequency fatigue resistance, suggests that the impaired endurance of fatigued muscle during voluntary activity primarily results from peripheral changes at low frequency. These findings also have implications for therapeutic electrical stimulation of muscle

Sullivan J.D., Olha A.E., Rohan I., and Schulz J. (1986) The properties of skeletal muscle. Orthop. Rev. 15, 349-363.
Abstract: The authors review the musculoskeletal system and the controversy that surrounds methods for improving and strengthening it. Disorders brought on by over utilization, deficient working habits, lack of appropriate maintenance care and intercurrent stress and fatigue from repetitious daily tasks and poor sleeping habits are recognized and discussed. Also discussed are muscle structure and its relation to the contractive state, muscle energy requirements, motor control, source of muscle strength and factors modulating it, training adaptations in skeletal muscle, methods of strength training, erogenic aids including anabolic steroids and electrical stimulation and the pathologic states in muscles

Svantesson U., Carlsson U., Takahashi H., Thomee R., and Grimby G. (1998) Comparison of muscle and tendon stiffness, jumping ability, muscle strength and fatigue in the plantar flexors. Scand. J. Med. Sci. Sports 8, 252-256.
Abstract: An isokinetic dynamometer was used to measure plantar flexion muscle strength at 60 degrees/s and 200 degrees/s in 10 healthy young men (mean age 25 years). Muscle and tendon stiffnesses were determined on the dynamometer by the use of electrical stimulation and passive stretch (200 degrees/s). Differences in jumping heights between squat and counter-movement jumps were calculated from flight times. The number of heel-rises performed until exhaustion, standing on one leg, were counted. Stepwise regression analysis showed that differences in jumping height increased with lower muscle strength and with higher muscle and tendon stiffnesses, indicating that elastic components may be of more importance in persons with lower muscle strength. The number of heel-rises was negatively dependant on

tendon stiffness, indicating that increased stiffness may enhance the development of fatigue

Svantesson U., Takahashi H., Carlsson U., Danielsson A., and Sunnerhagen K.S. (2000) Muscle and tendon stiffness in patients with upper motor neuron lesion following a stroke. Eur. J. Appl. Physiol 82, 275-279.
Abstract: The objective of this study was to investigate muscle and tendon stiffness in the triceps surae muscles in patients who had previously had a stroke. The participants were 12 men showing slight to moderate degrees of muscle tonus in the affected leg. All patients showed minimal or no overt clinical motor symptoms, and all walked without mechanical aid. Muscle strengths in isometric and isokinetic activities were measured, as was passive resistance during plantarflexion in each leg. Walking speed was also measured. Evaluations of physical performance and muscle tone were made. Muscle and tendon stiffness was calculated from measurements whilst passively stretching during electrical stimulation, separately for each leg. Muscle strength was significantly higher in the non-affected than in the affected leg. Muscle stiffness was significantly higher in the affected leg than in the non-affected leg. Tendon stiffness was significantly higher in the non-affected than in the affected leg. The higher muscle stiffness in the affected leg might enhance the possibility for storing elastic energy during preactivation. Lower tendon stiffness in the affected leg might reduce the development of fatigue in movements at low velocities

Van Cutsem M., Duchateau J., and Hainaut K. (1998) Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. J. Physiol 513 (Pt 1), 295-305.
Abstract: 1. The adaptations of the ankle dorsiflexor muscles and the behaviour of single motor units in the tibialis anterior in response to 12 weeks of dynamic training were studied in five human subjects. In each training session ten series of ten fast dorsiflexions were performed 5 days a week, against a load of 30-40% of the maximal muscle strength. 2. Training led to an enhancement of maximal voluntary muscle contraction (MVC) and the speed of voluntary ballistic contraction. This last enhancement was mainly related to neural adaptations since the time course of the muscle twitch induced by electrical stimulation remained unaffected. 3. The motor unit torque, recorded by the spike- triggered averaging method, increased without any change in its time to peak. The orderly motor unit recruitment (size principle) was preserved during slow ramp contraction after training but the units were activated earlier and had a greater maximal firing frequency during voluntary ballistic contractions. In addition, the high frequency firing rate observed at the onset of the contractions was maintained during the subsequent spikes after training. 4. Dynamic training induced brief (2-5 ms) motor unit interspike intervals, or 'doublets'. These doublets appeared to be different from the closely spaced (+/-10 ms) discharges usually observed at the onset of the ballistic contractions. Motor units with different recruitment thresholds showed doublet discharges and the percentage of the sample of units firing doublets was increased by training from 5.2 to 32.7%. The presence of these discharges was observed not only at the onset of the series of spikes but also later in the electromyographic (EMG) burst. 5. It is likely that earlier motor unit activation, extra doublets and enhanced maximal firing rate contribute to the increase in the speed of voluntary muscle contraction after dynamic training

van der L.L., Boks L.M., van Wezel B.M., Goris R.J., and Duysens J.E. (2000) Leg muscle reflexes mediated by cutaneous A-beta fibres are normal during gait in reflex

sympathetic dystrophy. Clin. Neurophysiol. 111, 677-685.
Abstract: OBJECTIVES: Reflex sympathetic dystrophy (RSD) is, from the onset, characterized by various neurological deficits such as an alteration of sensation and a decrease in muscle strength. We investigated if afferent A-beta fibre-mediated reflexes are changed in lower extremities affected by acute RSD.METHODS: The involvement of these fibres was determined by analyzing reflex responses from the tibialis anterior (TA) and biceps femoris (BF) muscles after electrical stimulation of the sural nerve. The reflexes were studied during walking on a treadmill to investigate whether the abnormalities in gait of the patients were related either to abnormal amplitudes or deficient phase-dependent modulation of reflexes. In 5 patients with acute RSD of the leg and 5 healthy volunteers these reflex responses were determined during the early and late swing phase of the step cycle.RESULTS: No significant difference was found between the RSD and the volunteers. During early swing the mean amplitude of the facilitatory P2 responses in BF and TA increased as a function of stimulus intensity (1.5, 2 and 2.5 times the perception threshold) in both groups. At end swing the same stimuli induced suppressive responses in TA. This phase-dependent reflex reversal from facilitation in early swing to suppression in late swing occurred equally in both groups. CONCLUSIONS: In the acute phase of RSD of the lower extremity there is no evidence for abnormal A-beta fibre-mediated reflexes or for defective regulation of such reflexes. This finding has implications for both the theory on RSD pathophysiology and RSD models, which are based on abnormal functioning of A-beta fibres

Wigerstad-Lossing I., Grimby G., Jonsson T., Morelli B., Peterson L., and Renstrom P. (1988) Effects of electrical muscle stimulation combined with voluntary contractions after knee ligament surgery. Med. Sci. Sports Exerc. 20, 93-98.
Abstract: The aim of the present study is to compare the effect of electrical muscle stimulation combined with voluntary muscle contractions with a program only with voluntary muscle contractions during immobilization in casts after anterior cruciate ligament surgery. Twenty-three patients, 7 women and 16 men with a mean age of 28 yr, were randomized into two groups: an experimental group (13 patients) and a control group (10 patients). Post-operatively, the patients were immobilized for 3 wk in a full leg cast with the knee flexed at an angle of 20 degrees to 30 degrees and then in a knee cast for another 3 wk. All patients had a standard program with quadriceps muscle contractions. In addition, the experimental group received electrical stimulation of the quadriceps muscle 4 X 10 min, 3 times.wk-1, at a frequency of 30 Hz. During each stimulation, the patients were requested to contract the quadriceps muscle voluntarily as well. When pre-operative measurements were compared with those at the end of the immobilization period (6 wk after the operation), a significantly larger reduction in the knee extension isometric muscle strength was found for the control group than for the experimental group. In comparisons of the data of the male subjects only, this difference was still seen to be significant. The cross-sectional area of the quadriceps muscle measured with computed tomography was significantly less reduced during the immobilization period in the experimental group than in the control group.(ABSTRACT TRUNCATED AT 250 WORDS)

Willett J.A., Gray S.D., and Carlsen R.C. (2000) Response to stimulation-evoked eccentric muscle contractions in hypertensive rats. Med. Sci. Sports Exerc. 32, 1390-1398.
Abstract: PURPOSE: The purpose of this study was to determine whether the

functional deficits observed in the skeletal muscles of adult, spontaneously hypertensive rats (SHR) arise because of an inability of injured muscles to regenerate normally in the hypertensive environment. METHODS: Force decline and recovery were evaluated in SHR tibialis anterior (TA) at various times after a series of 192 eccentric contractions (EC). EC were produced by supramaximal electrical stimulation of the sciatic nerve in anesthetized rats. Experiments compared TA muscles

Yamamoto K., Ohnishi A., Noda S., Umezaki H., and Yamamoto T. (1989) [An autopsy case of carcinomatous sensory neuropathy associated with gastric adenosquamous carcinoma]. Rinsho Shinkeigaku 29, 493-496.
Abstract: A 61-year-old man was admitted on May 1986 with complaints of hypesthesia and pain in the both legs, and of progressive difficulty in walking. Physical examination was unremarkable. On neurological examination, deep tendon reflexes were decreased in all extremities without pathological reflexes. Vibration sense was decreased severely at the medial malleolus and moderately at the anterior superior iliac spine. Joint sensation of the toes was moderately decreased. Light touch, temperature discrimination, and pinprick sensation were slightly decreased on fingers bilaterally and distal to the middle part of both legs. Muscle strength was normal. His gait was unsteady and Romberg's sign was positive. Finger to nose test and heel to knee test were mildly disturbed bilaterally. The sural nerve action potential was not elicited on electrical stimulation. Laboratory studies for malignancy showed gastric cancer. Only July 4, he underwent subtotal gastrectomy. Histologically it showed adenosquamous carcinoma. Postoperatively gait disturbance and pain in both legs improved slightly. Peak latencies of P2 of SEP following right and left posterior tibial nerve stimulation were 47. 9 msec and 48.8 msec on February 14, and 44.5 msec and 43.9 msec on October 6, 1986, respectively, and their postoperative shortening was evident. He died of multiple liver and lung metastasis of the gastric cancer in November 28, 1986. At autopsy, tumor metastasis were noted in liver, lung and perigastroduodenal and retroperitoneal lymph nodes.(ABSTRACT TRUNCATED AT 250 WORDS)

Yue G.H., Ranganathan V.K., Siemionow V., Liu J.Z., and Sahgal V. (1999) Older adults exhibit a reduced ability to fully activate their biceps brachii muscle. J. Gerontol. A Biol. Sci. Med. Sci. 54, M249-M253.
Abstract: BACKGROUND: Voluntary muscle strength declines significantly in older adults. One contributing factor to the strength loss is muscle atrophy developed in old age. Whether the ability to maximally activate the muscle decreases with age, however, is unknown. This study was intended to determine if the central nervous system command to maximally activate the biceps brachii muscle deteriorates with age. METHODS: Electrical stimulation pulses were applied to the skin overlying the biceps brachii muscle during maximal voluntary elbow-flexion contractions. The magnitude of force evoked on the maximal voluntary force was measured to determine the activation level (AL) of the muscle. RESULTS: The AL was 94% for the elderly group and 97% for the young group (100% AL indicates complete activation). The AL for both the elderly and young groups was significantly ($p<.05$) lower than 100%. The AL of the elderly group was significantly ($p<.05$) lower than that of the young group. CONCLUSIONS: The loss of voluntary strength in older adults is a mixed result of muscle atrophy and a reduced ability to fully activate muscle

Zupan A. (1992) Long-term electrical stimulation of muscles in children with Duchenne and Becker muscular dystrophy. Muscle Nerve 15, 362-367.
Abstract: Nine children suffering from progressive muscular dystrophy (7 Duchenne and 2 Becker) were included in a program of low-frequency electrical stimulation (LFES) of the right tibialis anterior (TA) muscle. Muscle strength and muscle fatigue were estimated by measuring torques in the ankle during attempts of maximal voluntary contraction (MVC) in the direction of dorsal flexion of the foot and during electrically evoked contractions (EEC). No important increase in the strength of the stimulated muscles was noticed in 4 boys whose muscles were stimulated for 3 months. The muscles of 5 boys who were subjected to electrical stimulation for 9 months showed an improvement; 6 measurements made during the stimulation program revealed that changes of torques in the ankle of the right stimulated extremity were significantly different (P less than 0.001) from the changes of torques in the ankle of the left nonstimulated extremity

Zupan A., Gregoric M., Valencic V., and Vandot S. (1993) Effects of electrical stimulation on muscles of children with Duchenne and Becker muscular dystrophy. Neuropediatrics 24, 189-192.
Abstract: Twelve children with progressive muscular dystrophy (10 Duchenne and 2 Becker type) were included in a low-frequency electrical stimulation (LFES) program of the right tibialis anterior (TA) muscle for three months. Muscle strength was estimated by measuring torques in the ankle during short attempts of maximal voluntary isometric contraction (MVIC) in the direction of dorsal flexion of the foot. Muscle fatigue was assessed by the decrease of force during sustained (1-minute) voluntary contraction. The measurements were carried out before the beginning of the stimulation program and immediately after its conclusion. At the end of the stimulation program there were higher torques in 10 out of 12 children in the stimulated leg. The increase in torques in the stimulated leg was statistically significant ($p < 0.01$). Regarding the fatigue of the stimulated muscle there was no change after the conclusion of stimulation