StimMaster Galaxy Ergometery Papers

[Electric stimulation in muscle training of the lower extremities in persons with spinal cord injuries]
Mohr T
Ugeskr Laeger. 2000 Apr 10; 162(15):2190-4.
Anaestesiologisk afdeling, Amtssygehuset i Glostrup.

Spinal cord injured persons have limited possibilities to perform physical training. By use of computerized, feed-back controlled electrical stimulation of the gluteal, the hamstrings and the quadriceps muscles cycle ergometry can be performed by the spinal cord injured individual. The cardiovascular demands of this training is higher than with voluntary upper body training using the intact innervated muscles. The inactivity related conditions caused by the spinal cord injury are reversed in part by regular electrically stimulated training. An increase is seen in maximal oxygen consumption, in the insulin stimulated glucose uptake and in the muscular mass and bone mineral content of the lower extremities. Electrically induced cycle ergometry is thoroughly investigated, relatively safe, but time consuming. As this training in addition results in the same well being as seen by training in able bodied individuals it can be recommended for motivated patients.

Insulin action and long-term electrically induced training in individuals with spinal cord injuries.
Mohr T, Dela F, Handberg A, Biering-Sorensen F, Galbo H, Kjaer M
Med Sci Sports Exerc. 2001 Aug; 33(8):1247-52.
Department of Medical Physiology, The Panum Institute, University of Copenhagen, Copenhagen, Denmark.

PURPOSE: Individuals with spinal cord injuries (SCI) have an increased prevalence of insulin resistance and type 2 diabetes mellitus. In able-bodied individuals, training with large muscle groups increases insulin sensitivity and may prevent type 2 diabetes mellitus. However, individuals with SCI cannot voluntarily recruit major muscle groups, but by functional electrical stimulation (FES) they can now perform ergometer bicycle training. METHODS: Ten subjects with SCI (35 +/- 2 yr (mean +/- SE), 73 +/- 5 kg, level of lesion C6--Th4, time since injury: 12 +/- 2 yr) performed 1 yr of FES cycling (30 min x d(-1), 3 d x wk(-1) (intensive training)). Seven subjects continued 6 months with reduced training (1 d x wk(-1) (reduced training)). A sequential, hyperinsulinemic (50 mU x min(-1) x m(-2) (step 1) and 480 mU x min(-1) x m(-2) (step 2)), euglycemic clamp, an oral glucose tolerance test (OGTT), and determination of GLUT 4 transporter protein in muscle biopsies were performed before and after training. RESULTS: Insulin-stimulated glucose uptake rates increased after intensive training (from 4.9 +/- 0.5 mg x min(-1) x kg(-1) to 6.2 +/- 0.6 mg x min(-1) x kg(-1) ($P < 0.008$) (step 1) and from 9.0 +/- 0.8 mg x min(-1) x kg(-1) to 10.6 +/- 0.8 mg x min(-1) x kg(-1) ($P = 0.103$) (step 2)). With the reduction in training, insulin sensitivity decreased to a similar level as before training ($P > 0.05$). GLUT 4 increased by 105% after intense training and decreased again with the training reduction. The subjects had impaired glucose tolerance before and after training, and neither glucose tolerance nor insulin responses to OGTT were significantly altered by training. CONCLUSIONS: Electrically induced bicycle training, performed three times per week increases insulin sensitivity and GLUT 4 content in skeletal muscle in subjects with SCI. A reduction in training to once per week is not sufficient to maintain these effects. FES training may have a role in the prevention of the insulin resistance syndrome in persons with SCI.

Peripheral vascular changes after electrically stimulated cycle training in people with spinal cord injury.
Gerrits HL, de Haan A, Sargeant AJ, van Langen H, Hopman MT
Arch Phys Med Rehabil. 2001 Jun; 82(6):832-9.
Institute for Fundamental and Clinical Human Movement Sciences, Vrije University Amsterdam, Amsterdam, the Netherlands.

OBJECTIVE: To test whether a short period of training leads to adaptations in the cross-sectional area of large conduit arteries and improved blood flow to the paralyzed legs of individuals with spinal cord injury (SCI). DESIGN: Before-after trial. SETTING: Rehabilitation center, academic medical center. PARTICIPANTS: Nine men with spinal cord lesions. INTERVENTION: Six weeks of cycling using a functional electrically stimulated leg cycle ergometer (FES-LCE). MAIN OUTCOME MEASURES: Longitudinal images and simultaneous velocity spectra were measured in the common carotid (CA) and femoral (FA) arteries using quantitative duplex Doppler ultrasound examination. Arterial diameters, peak systolic inflow volumes (PSIVs), mean inflow volumes (MIVs), and a velocity index (VI), representing the peripheral resistance, were obtained at rest. PSIVs and VI were obtained during 3 minutes of hyperemia following 20 minutes of FA occlusion. RESULTS: Training resulted in significant increases in diameter ($p < .01$), PSIVs ($p < .01$), and MIVs ($p < .05$), and reduced VI ($p < .01$) of the FA, whereas values in the CA remained unchanged. Postocclusive hyperemic responses were augmented, indicated by significantly higher PSIVs ($p < .01$) and a trend toward lower VI. CONCLUSION: Six weeks of FES-LCE training increased the cross-sectional area of large conduit arteries and improved blood flow to the paralyzed legs of individuals with SCI.

The effect of early therapeutic electrical stimulation on bone mineral density in the paralyzed limbs of the rabbit.
Lee YH, Rah JH, Park RW, Park CI
Yonsei Med J. 2001 Apr; 42(2):194-8.
Department of Rehabilitation Medicine, Yonsei University Wonju College of Medicine, Korea.

The purpose of this animal experiment was to evaluate the changes of bone mineral density in paralyzed limbs, and to assess the effects of electrically stimulating muscle contraction upon bone mineral density (BMD) in paralyzed limbs during the four week period immediately following spinal cord injury (SCI). Ten rabbits were used for the study, spinal cords were totally transected at the T11 spine level. The paralyzed quadriceps femoris of one limb was contracted by electrical stimulation for 60-minutes daily, while the other side was not stimulated as a control. The BMD of each lower limb was measured by Dual Photon Absorptiometry before and four weeks after acute SCI. BMD of both limbs decreased in all rabbits four weeks after SCI. The decrease in BMD for stimulated and non-stimulated limbs was 6.130 +/- 3.212% and 9.098 +/- 3.831%, respectively during the four-week period after SCI. The BMD of stimulated limbs decreased significantly less than that of the non-stimulated limbs. Electrically induced muscular contraction reduced bone mineral loss in the paralyzed limb during the early stage of SCI in the rabbit.

Effects of electrical stimulation leg training during the acute phase of spinal cord injury: a pilot study.
Crameri RM, Weston AR, Rutkowski S, Middleton JW, Davis GM, Sutton JR
Eur J Appl Physiol. 2000 Nov; 83(4 -5):409-15.

School of Exercise and Sport Science, Faculty of Health Sciences, The University of Sydney, Lidcombe, NSW, Australia.

Four individuals with a spinal cord injury underwent 16 weeks of isometric electrical stimulation training to both legs for 60 min, five times per week during the first 5 months after injury, while two SCI individuals remained untrained. A baseline biopsy sample of the vastus lateralis muscle was obtained within 1 month of injury, and another biopsy sample was taken after a further 16 weeks. The untrained, paralyzed skeletal muscle displayed a reduction in (1) type I fibers (from 50% to 9%), (2) myosin heavy chain (MHC) I (from 27% to 6%), and (3) fiber cross-sectional area of type I, type IIA and type IIX fibers (-62%, -68%, and -55%, respectively) when compared to the baseline sample of muscle taken within 1 month of injury. In contrast, the trained group showed smaller alterations in type I fibers (from 49% to 40%) and MHC I composition (from 39% to 25%), while fiber cross-sectional area was similar to baseline levels for type I, type IIA and type IIX fibers (-3%, -8%, and -4%, respectively). In conclusion, electrical stimulation training can largely prevent the adverse effects of a spinal cord injury upon paralyzed human skeletal muscle if applied soon after the injury.

FES cycling may promote recovery of leg function after incomplete spinal cord injury.
Donaldson N, Perkins TA, Fitzwater R, Wood DE, Middleton F
Spinal Cord. 2000 Nov; 38(11):680-2.
Department of Medical Physics and Bioengineering, University College London, UK.

STUDY DESIGN: Single subject pilot. OBJECTIVES:(i) To see whether strength and endurance for recreational cycling by functional electrical stimulation (FES) are possible following spinal cord injury (SCI). (ii) To develop the equipment for FES-cycling. SETTING: England. METHODS: Near-isometric or cycling exercise was performed by the incomplete SCI subject at home. RESULTS: After training for an average of 21 min per day for 16 months, the stimulated muscles increased in size and the subject was able to cycle for 12 km on the level. Surprisingly, there was a substantial increase in the measured voluntary strength of the knee extensors and the subject reports improved leg function. CONCLUSION: FES-cycling may promote recovery after incomplete spinal cord injury. If so, it offers the possibility of being a convenient method for widespread use.

Quadriceps muscle deoxygenation during functional electrical stimulation in adults with spinal cord injury.
Bhambhani Y, Tuchak C, Burnham R, Jeon J, Maikala R
Spinal Cord. 2000 Oct; 38(10):630-8.
Faculty of Rehabilitation Medicine, University of Alberta, Edmonton, Canada

STUDY DESIGN: Cross-sectional study comparing healthy subjects with age and gender matched subjects with spinal cord injury (SCI, injury levels from C5 to T12). OBJECTIVES: To compare the acute cardiorespiratory responses and muscle oxygenation trends during functional electrical stimulation (FES) cycle exercise and recovery in the SCI and healthy subjects exercising on a mechanical cycle ergometer. SETTING: Seven volunteers in each group participated in one exercise test at the Rick Hansen Center, University of Alberta, Edmonton, Canada. METHODS: Both groups completed a stagewise incremental test to voluntary fatigue followed by 2 min each of active and passive recovery. Cardiorespiratory responses were continuously monitored using an automated metabolic cart and a wireless heart rate monitor. Tissue absorbency, an index of muscle oxygenation, was monitored non-invasively from

the vastus lateralis using near infrared spectroscopy. RESULTS: The healthy subjects showed significant (PY0.05) increases in the oxygen uptake (VO2), heart rate (HR) and ventilation rate (VE) from rest to maximal exercise. The SCI subjects showed a twofold increase in VO2 (P>0.05), a threefold increase in VE(P<0.05) and a 5 beats/min increase in HR (P>0.05) from the resting value. The SCI subjects demonstrated a lesser degree (P<0.05) of muscle deoxygenation than the healthy subjects during the transition from rest to exercise. Regression analysis indicated that the rate of decline in muscle deoxygenation with respect to the VO2 was significantly (P<0.05) faster in the SCI subjects compared to healthy subjects. CONCLUSIONS: FES exercise in SCI subjects elicits: (a) modest increases in the cardiorespiratory responses when compared to resting levels; (b) lower degree of muscle deoxygenation during maximal exercise, and (c) faster changes in muscle deoxygenation with respect to the VO2 during exercise when compared to healthy subjects.

Electrical stimulation: can it increase muscle strength and reverse osteopenia in spinal cord injured individuals?
Belanger M, Stein RB, Wheeler GD, Gordon T, Leduc B
Arch Phys Med Rehabil. 2000 Aug; 81(8):1090-8.
Departement de Kinanthropologie, Universite du Quebec a Montreal, Canada.

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.

Functional electrical stimulation of abdominal muscles to augment tidal volume in spinal cord injury.
Stanic U, Kandare F, Jaeger R, Sorli J
IEEE Trans Rehabil Eng. 2000 Mar; 8(1):30-4.
Institute Jozef Stefan, Ljubljana, Slovenia.

Functional electrical stimulation (FES) of abdominal muscles as a method of enhancing ventilation was explored in six neurologically intact subjects and five subjects with spinal cord injury (SCI) who had levels of injury between C4 and C7. Pulmonary ventilation was augmented in both groups predominantly due to an increase in tidal volume. The average increase in tidal volume during FES for the neurologically intact group was 350 ml, while in the SCI group it was 220 ml. The FES caused active volume decreases in both the lower thorax and upper abdomen, which together appear to be the mechanism behind the increases seen in tidal volume. Therefore, the proposed method might be useful in future clinical practice. The results indicate that FES of

abdominal muscles should be more thoroughly explored as a potential technique of ventilatory support in SCI. The results also point to the necessity for further studies of maintaining the condition of the chest wall in the pulmonary rehabilitation of individuals with tetraplegia.

Functional electrical stimulation effect on orthostatic hypotension after spinal cord injury.
Sampson EE, Burnham RS, Andrews BJ
Arch Phys Med Rehabil. 2000 Feb; 81(2):139-43.
Division of Physical Medicine & Rehabilitation, Faculty of Medicine, University of Alberta, Edmonton, Canada.

OBJECTIVE: To investigate the possibility of using functional electrical stimulation (FES) to control orthostatic hypotension in patients with spinal cord injury (SCI) and to clarify the mechanism of the response. DESIGN: Subjects were tilted by 10 degree increments with varying intensities of lower-extremity FES. Stimulation over muscles was compared to stimulation over noncontractile sites. SETTING: Physical therapy department of a major rehabilitation center. PATIENTS: Six patients with SCI above T6 (3 with recent injury recruited consecutively from an inpatient spinal cord rehabilitation unit, and 3 from the community with longstanding injury, recruited as volunteers). MAIN OUTCOME MEASURES: Blood pressure, heart rate, and perceived presyncope score recorded at each tilt angle and analyzed using a multivariate analysis of variance statistical methodology. RESULTS: Systolic and diastolic blood pressure increased with increasing stimulation intensities (systolic, p = .001; diastolic, p = .0019) and decreased with increasing angle of tilt (p < .001) regardless of the site of stimulation. Subjects tolerated higher angles of incline with electrical stimulation than without (p = .03). CONCLUSIONS: FES causes a dose-dependent increase in blood pressure independent of stimulation site that may be useful in treating orthostatic hypotension.

Increasing muscle mass in spinal cord injured persons with a functional electrical stimulation exercise program.
Scremin AM, Kurta L, Gentili A, Wiseman B, Perell K, Kunkel C, Scremin OU
Arch Phys Med Rehabil. 1999 Dec; 80(12):1531-6.
Department of Physical Medicine and Rehabilitation, University of California at Los Angeles School of Medicine, USA.

OBJECTIVE: To determine the magnitude of changes in muscle mass and lower extremity body composition that could be induced with a regular regimen of functional electrical stimulation (FES)-induced lower-extremity cycling, as well as the distribution of changes in muscle mass among the thigh muscles in persons with spinal cord injury (SCI). STUDY DESIGN: Thirteen men with neurologically complete motor sensory SCI underwent a 3-phase, FES-induced, ergometry exercise program: phase 1, quadriceps strengthening: phase 2, progressive sequential stimulation to achieve a rhythmic pedaling motion (surface electrodes placed over the quadriceps, hamstrings, and gluteal muscles); phase 3, FES-induced cycling for 30 minutes. Participants moved from one phase to the next when they met the objectives for the current phase. MEASURES: Computed tomography of legs to assess muscle cross-sectional area and proportion of muscle and adipose tissue. Scans were done at baseline (before subjects started the program), at first follow-up, typically after 65.4+/-5.6 (SD) weekly sessions, and at second follow-up, typically after 98.1+/-9.1 sessions. RESULTS: Increases in cross-sectional areas were found in the following muscles: rectus femoris (31%, p<.001). sartorius (22%, p<.025), adductor magnus-hamstrings (26%, p<.001), vastus lateralis (39%, p = .001), vastus medialis-intermedius (31%, p = .025). Cross-sectional area of adductor longus and gracilis muscles did not change. The ratio of muscle to

adipose tissue increased significantly in thighs and calves. There was no correlation among the total number of exercise sessions and the magnitude of muscle hypertrophy. CONCLUSIONS: Muscle cross-sectional area and the muscle to adipose tissue ratio of the lower extremities increased during a regular regimen of 2.3 FES-induced lower extremity cycling sessions weekly. The distribution of changes was related to the proximity of muscles to the stimulating electrodes.

Functional electrical stimulation exercise increases GLUT-1 and GLUT-4 in paralyzed skeletal muscle.
Chilibeck PD, Bell G, Jeon J, Weiss CB, Murdoch G, MacLean I, Ryan E, Burnham
Metabolism. 1999 Nov; 48(11):1409-13.
Faculty of Physical Education and Recreation, University of Alberta, Edmonton, Canada.

The study purpose was to determine the effect of functional electrical stimulation (FES)-leg cycle ergometer training (30 minutes on 3 d/wk for 8 weeks) on the GLUT-1 and GLUT-4 content of paralyzed skeletal muscle. Biopsy samples of vastus lateralis muscle were obtained pre- and post-training from five individuals with motor-complete spinal cord injury ([SCI] four men and one woman aged 31 to 50 years, 3 to 25 years postinjury involving C5-T8). Western blot analysis indicated that GLUT-1 increased by 52% and GLUT-4 increased by 72% with training ($P < .05$). This coincided with an increase in the muscle oxidative capacity as indicated by a 56% increase in citrate synthase (CS) activity ($P < .05$) and an improvement in the insulin sensitivity index as determined from oral glucose tolerance tests ($P < .05$). It is concluded that FES endurance training is effective to increase glucose transporter protein levels in paralyzed skeletal muscle of individuals with SCI.

Long-term adaptation to electrically induced cycle training in severe spinal cord injured individuals
Mohr T Andersen JL Biering-Sorensen F Galbo H Bangsbo J Wagner A Kjaer
Spinal Cord 1997 Apr;35(4):262]

Spinal cord injured (SCI) individuals most often contract their injury at a young age and are deemed to a life of more or less physical inactivity. In addition to the primary implications of the SCI, severe SCI individuals are stigmatized by conditions related to their physically inactive lifestyle. It is unknown if these inactivity related conditions are potentially reversible and the aim of the present study was, therefore, to examine the effect of exercise on SCI individuals. Ten such individuals (six with tetraplegia and four with paraplegia; age 27-45 years; time since injury 3-23 years) were exercise trained for 1 year using an electrically induced computerized feedback controlled cycle ergometer. They trained for up to three times a week (mean 2.3 times), 30 min on each occasion. The gluteal, hamstring and quadriceps muscles were stimulated via electrodes placed on the skin over their motor points. During the first training bouts, a substantial variation in performance was seen between the subjects. A majority of them were capable of performing 30 min of exercise in the first bout; however, two individuals were only able to perform a few minutes of exercise. After training for 1 year all of the subjects were able to perform 30 min of continuous training and the work output had increased from 4 +/- 1 (mean +/- SE) to 17 +/- 2 Kilo Joules per training bout ($P < 0.05$). The maximal oxygen uptake during electrically induced exercise increased from 1.20 +/- 0.08 litres per minute measured after a few weeks habituation to the exercise to 1.43 +/- 0.09 litres per minute after training for 1 year ($P < 0.05$). Magnetic resonance cross sectional images of the thigh were performed to estimate muscle mass and an

increase of 12% (mean, P < 0.05) was seen in response to 1 year of training. In biopsies taken before exercise various degrees of atrophy were observed in the individual muscle fibres, a phenomenon that was partially normalized in all subjects after training. The fibre type distribution in skeletal muscles is known to shift towards type IIB fibres (fast twitch, fast fatiguable, glycolytic fibres) within the first 2 years after the spinal cord injury. The muscle in the present investigation contained of 63% myosin heavy chain (MHC) isoform IIB, 33% MHC isoform IIA (fast twitch, fatigue resistant) and less than 5% MHC isoform I (slow twitch) before training. A shift towards more fatigue resistant contractile proteins was found after 1 year of training. The percentage of MHC isoform IIA increased to 61% of all contractile protein and a corresponding decrease to 32% was seen in the fast fatiguable MHC isoform IIB, whereas MHC isoform I only comprised 7% of the total amount of MHC. This shift was accompanied by a doubling of the enzymatic activity of citrate synthase, as an indicator of mitochondrial oxidative capacity. It is concluded that inactivity- associated changes in exercise performance capacity and skeletal muscle occurring in SCI individuals after injury are reversible, even up to over 20 years after the injury. It follows that electrically induced exercise training of the paralysed limbs is an effective rehabilitation tool that should be offered to SCI individuals in the future.

Increased bone mineral density after prolonged electrically induced cycle training of paralyzed limbs in spinal cord injured man.
Mohr T Podenphant J Biering-Sorensen F Galbo H Thamsborg G Kjaer M
Calcif Tissue Int (1997 Jul) 61(1):22-5

Spinal cord injured (SCI) individuals have a substantial loss of bone mass in the lower limbs, equaling approximately 50% of normal values in the proximal tibia, and this has been associated with a high incidence of low impact fractures. To evaluate if this inactivity-associated condition in the SCI population can be reversed with prolonged physical training, ten SCI individuals [ages 35.3 +/- 2.3 years (mean +/- standard error [SE]); post injury time: 12.5 +/- 2.7 years, range 2-24 years; level of lesion: C6-Th4; weight: 78 +/- 3.8 kg] performed 12 months of Functional Electrical Stimulated (FES) upright cycling for 30 min per day, 3 days per week, followed by six months with only one weekly training session. Bone mineral density (BMD) was determined before training and 12 and 18 months later. BMD was measured in the lumbar spine, the femoral neck, and the proximal tibia by dual energy absorptiometry (DEXA, Nordland XR 26 MK1). Before training, BMD was in the proximal tibia (52%), as well as in the femoral neck, lower in SCI subjects than in controls of same age (P < 0.05). BMD of the lumbar spine did not differ between groups (P > 0.05). After 12 months of training, the BMD of the proximal tibia had increased 10%, from 0.49 +/- 0.04 to 0. 54 +/- 0.04 g/cm2 (P < 0.05). After a further 6 months with reduced training, the BMD in the proximal tibia no longer differed from the BMD before training (P > 0.05). No changes were observed in the lumbar spine or in the femoral neck in response to FES cycle training. It is concluded that in SCI, the loss of bone mass in the proximal tibia can be partially reversed by regular long-term FES cycle exercise. However, one exercise session per week is insufficient to maintain this increase.

Barstow TJ, Scremin AM, Mutton DL, Kunkel CF, Cagle TG, Whipp BJ
Med Sci Sports Exerc. 1996 Oct; 28(10):1221-8.
Department of Medicine, Harbor-UCLA Medical Center, Torrance, CA 90509, USA.
We examined the ability of patients with spinal cord injury to undergo adaptations to chronic exercise training (cycle ergometry) invoked by functional electrical stimulation (FES) of the legs. Nine such patients performed incremental and constant work rate exercise before and after

exercise training. Exercise sessions averaged 2.1 +/- 0.4/wk, and consisted of 30 min/session of continuous FES recumbent cycling with increasing work rate as tolerated. Peak VO2 and peak work rate significantly improved with training. Peak VO2 was significantly correlated with peak heart rate both before and after training ($r = 0.97$ pre and 0.85 post, $P < 0.01$ for both). The time course of the VO2, VCO2 and VE responses to constant-load exercise (unloaded cycling) and in recovery (mean response time MRT) were very long prior to training, and became significantly faster following training. However, there was no correlation between percentage improvement in either MRTon or MRToff for VO2 and the percentage increase in peak VO2. Exercise tolerance in these patients with spinal cord injury appears to be a direct function of the ability to increase heart rate. Further, exercise training can elicit significant improvements in both exercise tolerance and in gas exchange kinetics, even when performed only twice per week. However, these improvements may be accomplished by different mechanisms.

Physiologic effects of functional electrical stimulation-induced exercises in spinal cord-injured individuals.
Ragnarsson KT
Clin Orthop (1988 Aug)(233):53-63

Spinal cord injury (SCI) results in multiple degenerative changes that may in part be related to physical inactivity. There are indications that some of these changes may be reversed by exercise and fitness training. Computerized functional electrical stimulation (FES) allows active exercise of limbs paralyzed by upper motor neuron lesions. Thirty SCI subjects safely participated in an FES-induced exercise program for lower extremity strengthening and endurance training. increased strength, endurance, and bulk of stimulated muscles were noted. The subjects were able to perform a greater amount of work on a lower extremity ergometer, both per unit of time and per length of time, indicating a training effect. A multistage stress test showed evidence that the subjects had increased their aerobic metabolism during the training program. Twitch time tests showed slowing of muscle contraction, and computed topography showed increased muscle density.

Functional electric stimulation: its efficacy and safety in improving pulmonary function and musculoskeletal fitness.
Arnold PB McVey PP Farrell WJ Deurloo TM Grasso AR In: Arch Phys Med Rehabil (1992 Jul) 73(7):665-8

The efficacy and safety of functional electric stimulation (FES) in improving cardiovascular and musculoskeletal fitness in individuals with spinal cord injury was evaluated. Ten males and two females aged 16 to 46 years began an FES program from three months to 22 years after injury. Seven patients had paraplegia and five had quadriplegia. The FES protocol consisted of three phases: (1) leg extension, the stimulation of the quadriceps muscle group only, first without and then with weights; (2) ergometry, the stimulation of quadriceps, hamstrings, and gluteal muscles to produce a bicycling motion; and (3) resistance, the addition of resistance during the bicycling motion described in phase 2. Values for tidal volume, oxygen consumption, and the respiratory quotient were obtained during each phase. Tidal volume and oxygen consumption levels increased significantly (p less than .001) from the start of FES to both the ergometry and the resistance phases. The respiratory quotient improved significantly (p less than .001) from the start of FES to resistance but not from the start of FES to ergometry. Thigh and calf girths were measured at the start of FES and during resistance. Thigh girths increased significantly from the beginning of the program to the resistance phase, p less than .002 for the right leg and p less than .001 for the left.

Calf girth, however, showed no significant increase. Based on these improvements and the absence of any serious complications, we believe that FES is an effective and safe method to improve cardiovascular and musculoskeletal fitness in individuals with spinal cord injury.

Physiologic responses of paraplegics and quadriplegics to passive and active leg cycle ergometry.
Figoni SF Rodgers MM Glaser RM Hooker SP Feghri PD Ezenwa BN Mathews T
J Am Paraplegia Soc (1990 Jul) 13(3):33-9

The purposes of this study were three-fold: (a) to determine acute physiologic responses of spinal cord injured (SCI) subjects to peak levels of leg cycle ergometry utilizing functional neuromuscular stimulation (FNS) of paralyzed leg muscles, (b) to determine the relative contributions of passive and active components of FNS cycling to the peak physiologic responses, and (c) to compare these physiologic responses between persons who have quadriplegia and those who have paraplegia. Thirty SCI subjects (17 quadriplegics and 13 paraplegics) performed a discontinuous graded FNS exercise test from rest to fatigue on an ERGYS 1 ergometer. Steady-state physiologic responses were determined by open-circuit spirometry, impedance cardiography with ECG, and auscultation. In the combined statistics of both groups, it was noted that peak FNS cycling significantly increased (from rest levels) mean oxygen uptake by 255%, arteriovenous O2 difference VO2 and VE, Q and a-vO2 and VCO by 69%, and stroke volume by 45%, while total peripheral vascular resistance decreased by 43%. Mean peak power output for paraplegics (15 W) was significantly higher than for quadriplegics (9 W), eliciting higher peak levels of pulmonary ventilation and sympathetically mediated hemodynamic responses such as cardiac output, heart rate, and systolic and diastolic arterial blood pressure. Passive cycling without FNS produced no statistically significant increases in physiologic responses above the resting level in either group.

Treatment of spinal spasticity by electrical stimulation.
Franek A Turczynski B Opara J
J Biomed Eng (1988 May) 10(3):266-70

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

A clinical exercise system for paraplegics using functional electrical stimulation.
Bremner LA Sloan KE Day RE Scull ER Ackland T
Paraplegia (1992 Sep) 30(9):647-55

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.

Muscle atrophy is prevented in patients with acute spinal cord injury using functional electrical stimulation.
Baldi JC Jackson RD Moraille R Mysiw WJ
Spinal Cord (1998 Jul) 36(7):463-9

Severe muscle atrophy occurs rapidly following traumatic spinal cord injury (SCI). Previous research shows that neuromuscular or 'functional' electrical stimulation (FES), particularly FES-cycle ergometry (FES-CE) can cause muscle hypertrophy in individuals with chronic SCI (> 1 year post-injury). However, the modest degree of hypertrophy in these already atrophied muscles has lessened earlier hopes that FES therapy would reduce secondary impairments of SCI. It is not known whether FES treatments are effective when used to prevent, rather than reverse, muscle atrophy in individuals with acute SCI. This study explored whether unloaded isometric FES contractions (FES-IC) or FES-CE decreased subsequent muscle atrophy in individual with acute SCI (< 3 months post-injury). Twenty-six subjects, 14-15 weeks post-traumatic SCI, were assigned to control, FES-IC, or FES-CE against progressively increasing resistance. Subjects were involved in the study for 3 or 6 months. Total body lean body mass (TB-LBM), lower limb lean body mass (LL-LBM), and gluteal lean body mass (G-LBM) were determined before the study, and at 3 and 6 months using dual energy X-ray absorptiometry (DEXA). Controls lost an average of 6.1%, 10.1%, 12.4%, after 3 months and 9.5%, 21.4%, 26.8% after 6 months in TB-LBM, LL-LBM and G-LBM respectively. Subjects in the FES-IC group consistently lost less lean body mass than controls, however, only 6 month G-LBM loss was significantly attenuated in this group relative to the controls. In the FES-CE group, LL-LBM and G-LBM loss were prevented at both 3 and 6 months, and TB-LBM loss was prevented at 6 months. In addition, FES- CE significantly increased G-LBM and LL-LBM after 6 months of training relative to pre-training levels. Within the control group, there was no significant relationship between LL-LBM loss (3 and 6 months) and the number of days between injury and baseline measurement. In summary, this study shows that FES-CE, but not FES- IC, training prevents muscle atrophy in acute SCI after 3 months of training, and causes significant hypertrophy after 6 months. The magnitude of differences in regionalized LBM between controls and FES- CE subject raises hopes that such treatment may indeed be beneficial in preventing secondary impairments of SCI if employed before extensive post-injury atrophy occurs.

Physiologic effects of electrical stimulation leg cycle exercise training in spinal cord injured persons.
Hooker SP Figoni SF Rodgers MM Glaser RM Mathews T Suryaprasad AG Gupta

Arch Phys Med Rehabil (1992 May) 73(5):470-6

The purpose of this study was to assess the physiologic training effects of functional electrical stimulation leg cycle ergometer (FES-LCE) exercise in persons with spinal cord injury (SCI) who were previously untrained in this activity. Ten persons with quadriplegia (C5 to C7) and eight with paraplegia (T4 to T11) performed FES-LCE training on an ERGYS I ergometer 10 to 30 minutes per day, 2 or 3 days per week for 12 to 16 weeks (36 total sessions). Training session power output (PO) ranged from 0.0W (no external resistance) to 30.6W. Each subject completed discontinuous graded FES-LCE and arm crank ergometer (ACE) tests before and after training for determinations of peak lower and upper extremity metabolic, pulmonary, and hemodynamic responses. Compared with pretraining, this SCI group exhibited significantly (p less than or equal to .05) higher posttraining peak PO (+45%), oxygen uptake ([O2], + 23%), pulmonary ventilation (+27%), heart rate (+11%), cardiac output ([Qt], + 13%) and significantly lower total peripheral resistance ([TPR], - 14%) during FES-LCE posttests. There were no significant changes in peak stroke volume (+6%), mean arterial pressure ([MAP], - 5%), or arteriovenous oxygen difference ([a-vO2diff], + 10%) during posttraining FES-LCE tests. In addition, no significant differences were noted for the peak level of any monitored variable during ACE
posttests after FES-LCE training. The rise in total vascular conductance, implied by the significant decrease in posttraining TPR during FES-LCE tests, denotes that a peripheral circulatory adaptation developed in the persons with SCI during FES-LCE exercise training.(ABSTRACT TRUNCATED AT 250 WORDS)

Physiologic responses to prolonged electrically stimulated leg-cycle exercise in the spinal cord injured.
Hooker SP Figoni SF Glaser RM Rodgers MM Ezenwa BN Faghri PD
Arch Phys Med Rehabil (1990 Oct) 71(11):863-9

This study determined the physiologic responses to prolonged functional neuromuscular stimulation (FNS) leg-cycle exercise in seven quadriplegic and seven paraplegic subjects. Each subject completed 30 minutes of continuous FNS leg cycling during which open-circuit spirometry, impedance cardiography, auscultation, and fingertip capillary blood sampling were used to assess metabolic and hemodynamic responses. Compared with resting values, oxygen uptake, carbon dioxide production, respiratory exchange ratio (RER), pulmonary ventilation, heart rate (HR), left ventricular stroke volume (SV), cardiac output (Qt), and blood lactate (La) concentration were significantly (p less than .05) elevated, whereas plasma volume, bicarbonate concentration, and pH were significantly decreased in both groups during prolonged FNS leg-cycle exercise. Mean arterial pressure remained unchanged in quadriplegic and paraplegic subjects during the prolonged FNS leg-cycle exercise bout. Persons with quadriplegia elicited significantly lower MAP and tended to have lower SV and Qt responses than persons with paraplegia, probably due to a higher degree of sympathetic dysfunction and circulatory hypokinesis during FNS leg-cycle exercise. All other physiologic variables responded similarly between groups. We speculate that the relative increases observed for HR (33% to 60%), SV (45% to 69%), and Qt (113% to 142%) during prolonged FNS leg-cycle exercise create a sufficient cardiac-volume load to promote central cardiovascular conditioning in persons with both quadriplegia and paraplegia. The La accumulation (4.7 to 5.2 mmol.L-1) in the spinal cord injured during prolonged FNS leg cycling is unusually high for the power output attained (5.2W and 6.1W for quadriplegia and paraplegia, respectively).(ABSTRACT TRUNCATED AT 250 WORDS)

Physiologic responses during functional electrical stimulation leg cycling and hybrid exercise in spinal cord injured subjects.
Mutton DL Scremin AM Barstow TJ Scott MD Kunkel CF Cagle TG
Arch Phys Med Rehabil (1997 Jul) 78(7):712-8

OBJECTIVES: (1) To determine if a hybrid exercise (leg plus arm) training program performed immediately after functional electrical stimulation (FES) leg cycle exercise (LCE) training would further improve aerobic capacity when compared with FES leg cycle training alone, and (2) to compare the submaximal responses occurring during both FES-LCE alone and hybrid exercise in the same SCI subjects. DESIGN: Nonrandomized control trial whereby subjects act as their own control. SETTING: Outpatient rehabilitation in a primary care hospital. PATIENTS: A volunteer sample (n = 11) of men 20 to 50 years old with complete spinal cord injury, free from cardiovascular and metabolic disease with spasticity. INTERVENTIONS: Three phases of exercise training: phase I, progressive FES-LCE to 30 minutes of exercise (n = 11); phase II, 35.2 +/- 16.2 sessions of FES-LCE (n = 11); phase III, 41.4 +/- 17.7 30-minute sessions of hybrid exercise (n = 8). MAIN OUTCOME MEASURES: (1) Aerobic capacity-a further increase after hybrid exercise when compared with FES-LCE alone; (2) submaximal physiologic parameters (oxygen uptake [VO2], heart rate [HR], blood lactate [BLa-])-measurement of these during constant work rate exercise and a training effect. RESULTS: VO2 (the body's ability to utilize oxygen) significantly improved ($p < .05$) after both FES- LCE and then further after hybrid training. Hybrid exercise training resulted in significantly ($p < .05$) greater work rates and VO2 values than both FES-LCE at baseline and training work rates. CONCLUSION: These subjects demonstrated that hybrid exercise performed twice a week provided sufficient intensity to improve aerobic capacity and provide a medium whereby patients with SCI can burn more calories than via FES-LCE alone. This has important implications for improving the health and fitness levels of individuals with SCI and may ultimately reduce their risk of cardiovascular disease.

Peak and submaximal physiologic responses following electrical stimulation leg cycle ergometer training.
Hooker SP Scremin AM Mutton DL Kunkel CF Cagle G
J Rehabil Res Dev (1995 Nov) 32(4):361-6

Eight males with spinal cord injury (SCI) participated in an exercise training program using neuromuscular electrical stimulation (NMES) leg cycle ergometry. Each subject completed a minimum of 24 (mean +/- SD = 38.1 +/- 17.2) 30-minute training sessions over a 19-week period. The initial work rate (WR) of 0 watts (W) of unloaded cycling was increased when appropriate with subjects exercising at 11.4 +/- 3.7 W (range = 6.1 W-18.3 W) at the end of the training program. Randomized block repeated measures ANOVA was used to compare pretraining and posttraining peak physiologic responses during graded NMES leg cycle tests and subpeak physiologic responses during 10 minutes of NMES leg cycle exercise at an absolute WR (0 W). A significant ($P <$ or $= 0.05$) increase was observed for peak VO2; (+10%, 1.29 +/- 0.30 to 1.42 +/- 0.39 1.min-1). No other statistically significant differences were noted for any other peak variable (VCO2, VO2 ml.kg-1 min-1, VE, WR, HR, RER) pre- to posttraining. During submaximal NMES leg cycle testing, a significant decrease was noted for RER (-9.2%, 1.19 +/- 0.14 to 1.08 +/- 0.09). No other submaximal variable (VO2 1.min-1, ml.kg-1.min-1, VCO2, HR, VE) showed significant changes as a result of the training. Although the improvement in peak VO2 was not as dramatic as those reported in previous studies, it appears that NMES leg cycle training performed two times per week can significantly enhance cardiorespiratory fitness.

Effects of electrically-stimulated exercise and passive motion on echocardiographically-derived wall motion and cardiodynamic function in tetraplegic persons.
Nash MS Bilsker MS Kearney HM Ramirez JN Applegate B Green BA
Paraplegia (1995 Feb) 33(2):80-9

The purposes of the study were (1) to characterize left ventricular wall motion, and the cardiodynamic and metabolic responses during electrical stimulation cycle ergometry (ESCE) exercise in tetraplegic people; (2) to test whether these responses linger into the post- exercise recovery period; and (3) to test whether they differ from those imposed by lower extremity continuous passive motion (CPM). Subjects were six tetraplegic males aged 25.8 +/- 3.1 (mean +/- SD) years with spinal cord injuries of 6.7 +/- 3.5 years' duration at the C5 and C6 levels (Frankel classifications A and B). On randomized non- consecutive days, subjects underwent either 30 min of steady-state exercise using transcutaneous electrically-stimulated contractions of bilateral quadriceps, hamstring, and gluteus muscle groups, or 30 min of continuous passive motion at 50 rpm. Data were taken at rest, min 15 and 30 of treatment, and min 5, 15, and 30 post-treatment. Stroke volume (SV) was measured echocardiographically as the product of the left ventricular outflow tract area and the integrated area under the left ventricular outflow tract flow-velocity curve acquired by doppler ultrasound. This value was multiplied by heart rate (HR) to determine the cardiac output (CO). Oxygen consumption (VO2) was monitored spirometrically, with arteriovenous oxygen difference (a-vO2DIFF) computed algebraically. Data were analyzed using repeated measures within-subjects design anaysis of variance, with significance accepted at the 0.05 level. Results showed five subjects had small hyperkinetic ventricles at rest that became more dynamic during ESCE than CPM. Though no systolic dysfunction was noted, all but one subject exhibited some degree of septal hypokinesis at rest and during exercise, possibly indicative of left ventricular noncompliance. Significant effects of condition (ESCE vs CPM), trial (measurement time point), and their interaction, were observed for CO ($P < 0.05$, 0.01, and 0.0001, respectively), HR ($P < 0.0001$, 0.05 and 0.005, respectively), and VO2 ($P < 0.001$, 0.05 and 0.005, respectively). A significant trial and condition by trial interaction was found for a-vO2DIFF ($P < 0.05$ and 0.0001, respectively). No effects for condition, trial or their interaction were found for SV or BPDIAS. Electrical stimulation cycle ergometry-treated subjects achieved peak VO2 of 712 +/- 300 ml min-1, 2.63 times baseline, with 56% elevation of a-vO2DIFF. Cardiac output increased from 3.5 +/- 1.51 min-1 to 6.0 +/- 2.11 min-1, an elevation solely attributable to a 57% increase in HR. Thus, both CO and a-vO2DIFF accounted for elevated VO2 during ESCE.(ABSTRACT TRUNCATED AT 400 WORDS)

Cardiovascular and metabolic responses to electrical stimulation-induced leg exercise in spinal cord injury.
Thomas AJ Davis GM Sutton JR
Methods Inf Med (1997 Dec) 36(4-5):372-5

Electrical stimulation-induced leg muscle contractions provide a useful model for examining the role of leg muscle neural afferents during low-intensity exercise in persons with spinal cord-injury and their able-bodied cohorts. Eight persons with paraplegia (SCI) and 8 non-disabled subjects (CONTROL) performed passive knee flexion/extension (PAS), electrical stimulation-induced knee flexion/extension (ES) and voluntary knee flexion/extension (VOL) on an isokinetic dynamometer. In CONTROLs, exercise heart rate was significantly increased during ES (94 +/- 6 bpm) and VOL (85 +/- 4 bpm) over PAS (69 +/- 4 bpm), but no changes were observed in SCI individuals. Stroke volume was

significantly augmented in SCI during ES (59 +/- 5 ml) compared to PAS (46 +/- 4 ml). The results of this study suggest that, in able-bodied humans, Group III and IV leg muscle afferents contribute to increased cardiac output during exercise primarily via augmented heart rate. In contrast, SCI achieve raised cardiac output during ES leg exercise via increased venous return in the absence of any change in heart rate.

Histochemical changes in muscle of individuals with spinal cord injury following functional electrical stimulated exercise training.
Chilibeck PD Jeon J Weiss C Bell G Burnham R
Spinal Cord (1999 Apr) 37(4):264-8

STUDY DESIGN: Longitudinal training. OBJECTIVES: To determine the effects of functional electrical stimulated (FES) leg cycle ergometer training on muscle histochemical characteristics in individuals with motor-complete spinal cord injury (SCI). SETTING: University of Alberta, Edmonton, Alberta, Canada. METHODS: Six individuals with motor-complete SCI (age 31-50 years; 3-25 years post-injury) trained using FES leg cycle ergometry for 30 min, 3 days per week for 8 weeks. Biopsies of the vastus lateralis muscle were obtained pre- and post-training and analyzed for fibre composition, fibre size and capillarization. RESULTS: The majority of muscle fibres were classified as type 2 pre- and post-training. Average fibre area increased 23% ($P<0.05$) and capillary number increased 39% ($P<0.05$) with training. As a result of these proportional increases, capillarization expressed relative to fibre area was unchanged with training. CONCLUSIONS: FES leg cycle ergometer training results in proportional increases in fibre area and capillary number in individuals with SCI.

The effects of neuromuscular stimulation-induced muscle contraction versus elevation on hand edema in CVA patients.
Faghri PD.
J Hand Ther. 1997 Jan-Mar;10(1):29-34.
Department of Health Promotion and Allied Health Sciences, University of Connecticut, School of Allied Health Storrs 06269-2101, USA.

The purpose of this study was to evaluate the efficacy of the use of neuromuscular stimulation (NMS)-induced contraction of the paralyzed muscles to produce an active muscle pump for removing excess fluid and compare its effect with elevation of the upper extremity. The effects of 30 minutes of NMS of the finger and wrist flexors and extensors were compared with the effects of 30 minutes of limb elevation alone. Each of eight cerebrovascular accident (CVA) patients with visible hand edema received both treatments, one on each of 2 consecutive days. Measures of hand and arm volume and upper and lower arm girth were taken before and after each treatment. Analyses comparing mean percentage change scores for both treatments showed large and significant treatment effects for all dependent measures. The finding suggests that NMS was more effective for reduction of hand edema than limb elevation alone for this sample of eight CVA patients.

Peripheral vascular changes after electrically stimulated cycle training in people with spinal cord injury.
Gerrits HL, de Haan A, Sargeant AJ, van Langen H, Hopman MT
Arch Phys Med Rehabil. 2001 Jun;82(6):832-9.
Institute for Fundamental and Clinical Human Movement Sciences, Vrije University Amsterdam, Amsterdam, the Netherlands. k_gerrits@fbw.vu.nl

OBJECTIVE: To test whether a short period of training leads to adaptations in the cross-sectional area of large conduit arteries and improved blood flow to the paralyzed legs of individuals with spinal cord injury (SCI). DESIGN: Before-after trial. SETTING: Rehabilitation center, academic medical center. PARTICIPANTS: Nine men with spinal cord lesions. INTERVENTION: Six weeks of cycling using a functional electrically stimulated leg cycle ergometer (FES-LCE). MAIN OUTCOME MEASURES: Longitudinal images and simultaneous velocity spectra were measured in the common carotid (CA) and femoral (FA) arteries using quantitative duplex Doppler ultrasound examination. Arterial diameters, peak systolic inflow volumes(PSIVs), mean inflow volumes (MIVs), and a velocity index (VI), representing the peripheral resistance, were obtained at rest. PSIVs and VI were obtained during 3 minutes of hyperemia following 20 minutes of FA occlusion. RESULTS: Training resulted in significant increases in diameter ($p < .01$), PSIVs ($p < .01$), and MIVs ($p < .05$), and reduced VI ($p < .01$) of the FA, whereas values in the CA remained unchanged. Postocclusive hyperemic responses were augmented, indicated by significantly higher PSIVs ($p < .01$) and a trend toward lower VI. CONCLUSION: Six weeks of FES-LCE training increased the cross-sectional area of large conduit arteries and improved blood flow to the paralyzed legs of individuals with SCI.

Effects of aging on neurogenic vasodilator responses evoked by transcutaneous electrical nerve stimulation: relevance to wound healing.
Khalil Z, Merhi M
J Gerontol A Biol Sci Med Sci. 2000 Jun; 55(6):B257-63.
National Ageing Research Institute, University of Melbourne, Victoria, Australia.

We have previously shown an age-related decline in the modulation of skin vascular reactivity by sensory nerves that correlates with a decline in wound repair efficacy. This study was designed to examine the possibility that improving the functional ability of aged sensory nerves using noninvasive transcutaneous electrical nerve stimulation (TENS) could also accelerate tissue repair. TENS of the sciatic nerve, combined with measuring blood flow responses in the rat hind-footpad using laser Doppler flowmetry, was used to establish the vascular effects. Following TENS (using parameters 20V, 5 Hz for 1 min), similar increases in vascular responses were obtained in both young (13.2+/-0.9 cm2) and old rats (11.6+/-2.3 cm2). In contrast, capsaicin-pretreated rats showed markedly diminished responses. Sympathetic fibers did not appear to modulate these sensory nerve responses. In the second part, a thermal wound was induced (using a CO2 laser) in the interscapular region of old rats (under anesthesia). In the active treatment group, TENS was applied twice daily for the initial 5 days, and the sham group received inactive TENS. Using the healing endpoint as the time when full wound contraction occurred, the active group required 14.7+/-0.2 days for complete healing, a significant improvement over the sham group (21.8+/-0.3 days). We contend that low-frequency TENS can improve the vascular response of old rats. In addition, wound healing in aged rats can be accelerated by peripheral activation of sensory nerves at low-frequency electrical stimulation parameters.

Epidural spinal cord electrical stimulation in diabetic critical lower limb ischemia.
Petrakis IE, Sciacca V
Title Abbreviation: J Diabetes Complications.
1999 Sep-Dec; Volume Issue: 13(5-6):293-9.
First Department of General Surgery, Policlinico Umberto I, University of Rome, La Sapienza, Rome, Italy.

Spinal cord stimulation (SCS) has been suggested to improve microcirculatory blood flow to relieve ischemic pain and to reduce amputation rate in patients with peripheral arterial occlusive disease (PAOD). The aim of this study was to evaluate the specific prognostic parameters in the prediction of successful SCS, in diabetic patients, performing a retrospective data analysis. To perform this evaluation, 64 diabetic patients (39 men, 25 women; mean age, 69 years) classified as Fontaine's stage III and IV, with PAOD, were treated with SCS for rest pain and trophic lesions with dry gangrene, after failed conservative or surgical treatment. In clinical controls, pedal transcutaneous oxygen tension (TcPO(2)), ankle/brachial blood pressure index (ABI), and toe pressure Doppler measurements were utilized to select and follow-up the patients. After 58 months of follow-up (range, 20-128 months), pain relief greater than 75% and limb salvage were achieved in 38 diabetic patients. A partial success was obtained in nine patients with pain relief greater than 50% and limb salvage for at least 6 months. The method failed in 17 patients or the device was removed due to technical problems, and the limb was amputated in these patients. TcPO(2) was assessed on the dorsum of the foot. Clinical improvement and SCS success were associated with increase of TcPO(2), before and after implantation. Limb salvage was achieved in the patients who had significant TcPO(2) increase within the 2 weeks of the testing period, independently of the stage of the disease. A TcPO(2) increase of more than 50% in the first 2 months after implantation was predictive of success, and was related to the presence of adequate paresthesias in the painful area during the trial period. TcPO(2) significantly increased after long-term follow-up in all patients with limb salvage (from 22.1 to 43.1 mm Hg in the rest pain patients, from 15.8 to 36.4 mm Hg in those with trophic lesions of less than 3 cm(2), and from 12.1 to 28.1 in those with trophic lesions of greater than 3 cm(2), ($p < 0.01$). ABI did not changed under stimulation. In diabetic patients with PAOD, the SCS increases the skin blood flow, is associated with significant pain relief, and could be proven an excellent alternative therapy, improving the life quality. Significant TcPO(2) increase within the 2-week test period, is a predictive index of therapy success and should be considered before the final decision in terms of cost effectiveness, before the permanent implantation.

Effects of transcutaneous nerve stimulation on the microcirculation in chronic leg ulcers.
Cosmo P, Svensson H, Bornmyr S, Wikstrom SO
Scand J Plast Reconstr Surg Hand Surg. 2000 Mar; 34(1):61-4.
Department of Plastic and Reconstructive Surgery, Malmo University Hospital, Sweden.

The purpose of this study was to find out to what extent transcutaneous electrical nerve stimulation (TENS) affects the blood flow in and around chronic lower leg ulcers, as measured with a new technique, laser Doppler imaging (LDI). Fifteen patients, mean age 73 years (range 38-85) with chronic leg ulcers of various causes participated in the study. The duration of the ulcers ranged from 3 months to 16 years. Low-frequency (2 Hz; 10-45 mA) TENS was given for 60 minutes. The changes in blood flow were measured every 5 minutes by LDI. After 60 minutes, mean blood flow had increased in the ulcer by 35%, and in the intact skin surrounding the ulcer by 15%. Even 15 minutes after the TENS had finished there was still a mean blood flow increase of 29% in the ulcer and 9% in the skin. The present results show that TENS has a stimulating effect on local blood circulation in and around chronic ulcers.

Effect of transcutaneous nerve stimulation on microcirculation in intact skin and blister wounds in healthy volunteers.

Wikstrom SO, Svedman P, Svensson H, Tanweer AS
Scand J Plast Reconstr Surg Hand Surg. 1999 Jun; 33(2):195-201.
Department of Plastic and Reconstructive Surgery, University Hospital MAS, Malmo, Sweden.

Healthy non-smoking volunteers participated in two experimental studies in which the circulatory changes induced by transcutaneous nerve stimulation (TENS) were quantified by two different methods. In experimental series 1 (intact skin), nine volunteers were given TENS on the left lower leg for 60 minutes on three occasions at different frequencies each time (2 Hz, 100 Hz, and sham). Changes in blood flow were assessed by laser Doppler imaging technique every five minutes. The mean blood flow increased by 40% during low frequency TENS and by 12% during high frequency TENS. There was no change in mean blood flow during sham stimulation. In experimental series 2 (blister wound), the circulatory changes induced by TENS were studied by intravital video microscopy and computerised image analysis in standard blister wounds on the lower leg. The microcirculatory blood flow, measured as red blood cell velocity (RBC-V) in 5-14 individual capillaries in each wound, was assessed before and during 45 minutes of TENS (2 Hz and 100 Hz). Mean RBC-V increased by 23% during low frequency TENS (n = 6) and by 17% during high frequency TENS (n = 8). The results show that: laser Doppler imaging and intravital video microscopy techniques can be used to study events at the microcirculatory level; the blister wound is an interesting new standard wound for use in clinical studies; and TENS stimulates the peripheral circulation.

FES and spasticity.
Stefanovska A, Vodovnik L, Gros N, Rebersek S, Acimovic-Janezic R.
IEEE Trans Biomed Eng. 1989 Jul;36(7):738-45.

A model of hemiplegic spasticity based on electromyographical and biomechanical parameters measured during passive muscle stretching is presented. Two components of spasticity can be distinguished--phasic and tonic. This classification depends on the pattern of stretch reflex activity which can be either phasic or tonic as well as on the muscle stretch/tension characteristic. Stretch reflex, as a control loop, is in phasic spasticity characterized by increased sensitivity to velocity of stretching. In tonic spasticity, sensitivity to length of stretching is increased. After the injury, phasic spasticity appears first and invokes monosynaptic reflex pathways. The intensity of tonic spasticity increases with the duration of disability and hence causes changes in muscle fiber biomechanical properties. The model mentioned above has been used to evaluate the effects of FES on spasticity. Hemiplegic patients with implanted peroneal nerve stimulator for gait correction were followed up for one year starting a week before implantation. Long-term use of FES resulted in decrease of tonic spasticity in both ankle joint antagonistic muscle groups. In stimulated tibialis anterior muscle, the phasic type of spasticity increased. To obtain the correlation between changes in spasticity and functional abilities of patients, the maximal voluntary isometric contraction of both muscle groups was also measured. An improvement in voluntary strength was also observed. This can be taken as additional evidence that tonic spasticity is of greater physiological and clinical significance than phasic spasticity. It may be concluded that use of FES can decrease tonic spasticity and, if applied early after the injury, can prevent the appearance of tonic spasticity.

The quantitative measurement of spasticity: effect of cutaneous electrical stimulation.
Seib TP, Price R, Reyes MR, Lehmann JF.
Arch Phys Med Rehabil. 1994 Jul;75(7):746-50.
University of Washington School of Medicine, Seattle.

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

Spasticity in spinal cord injured patients: 1. Short-term effects of surface electrical stimulation.
Robinson CJ, Kett NA, Bolam JM.
Arch Phys Med Rehabil. 1988 Aug;69(8):598-604.
Rehabilitation Research and Development Center, Veterans Administration Hospital, Hines, IL 60141.

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

Treatment of spinal spasticity by electrical stimulation.
Franek A, Turczynski B, Opara J.
J Biomed Eng. 1988 May;10(3):266-70.
Department of Biophysics, Silesian School of Medicine, Zabrze-Rokitnica, Poland.

We present the results and the methodology of trials using transcutaneous electrical stimulation. The aim of our work was to decrease spasticity in 44 patients with traumatic damage to the spinal cord; 35 non-electrically

stimulated spastics were used as controls. Both groups were randomly selected from inpatients in the Paraplegic Department at the Hospital Rehabilitation Centre. This electrical stimulation procedure leads to a long-lasting reduction in spasticity, an increased range of passive and active movements, the facilitation of lost functions, an improvement in breathing, an increase in pulmonary capacity, the reappearance of some neurological reflexes, and a diminution of supersensitivity to skin irritation. Blood pressure and neurogenic bladder functions were restored to normal. In addition to clinical observations, we investigated muscle force and the electromyogram; other measurements used in the trials involved the use of a specially adapted neurological hammer, a pendulum test, spirometry, cystometry, sphincterometry and biochemical estimations.

Effects of surface spinal cord stimulation on spasticity and quantitative assessment of muscle tone in hemiplegic patients.
Wang RY, Tsai MW, Chan RC.
Am J Phys Med Rehabil. 1998 Jul-Aug;77(4):282-7.
Faculty of Physical Therapy, National Yang-Ming University, Shih-Pai, Taipei, Taiwan, Republic of China.

Spasticity after a stroke interferes with the normal function of a limb. Electric stimulation has been used in a variety of ways to decrease spasticity. The purposes of this study were (1) to quantify the effectiveness of electric stimulation on decreasing ankle spasticity and (2) to develop a quantitative assessment of muscle tone, which could be replicated in the clinic. Ten patients with hemiparesis resulting from ischemic stroke participated in the study according to the selection criteria. Their mean age was 57 yr, with a mean stroke interval of 12.5 months. Patients received electric stimulation for 45 min through surface electrodes applied to the skin in the 12th thoracic and 1st lumbar areas. All patients received five electric stimulation treatment sessions. The electrical pulses were amplitude modulated frequency beat with a carry frequency of 2500 Hz and a stimulation frequency of 20 Hz. The stimulation intensity was adjusted to each patient to produce a sensory stimulation. The pre- and posttreatment evaluation included surface electromyography activity during passive ankle dorsiflexion, passive ankle dorsiflexion resistance at different angular velocities, as measured by an isokinetic machine and the modified Ashworth scale. Our results indicate that the surface spinal cord stimulation with middle stimulation on the skin of 12th thoracic and first lumbar area is effective in reducing calf muscle spasticity of hemiplegic patients. The isokinetic torque measures for spasticity are a sensitive tool to document the effects of the treatment.

Relief of hemiparetic spasticity by TENS is associated with improvement in reflex and voluntary motor functions.
Levin MF, Hui-Chan CW.
Electroencephalogr Clin Neurophysiol. 1992 Apr;85(2):131-42.
School of Physical and Occupational Therapy, Faculty of Medicine, McGill University, Montreal, Que, Canada.

Our previous studies showed that a single 45 min application of transcutaneous electrical nerve stimulation (TENS) prolonged soleus H and stretch reflex latencies in hemiparetic subjects. In addition, 9 daily 30 min TENS applications enhanced vibratory inhibition of the H reflex and tended to decrease hyperactive stretch reflexes. These findings suggested that longer-term TENS may be effective in reducing hemiparetic spasticity. Our present objectives were 2-fold: to determine whether longer-term repetitive TENS stimulation would lead to a reduction in clinical spasticity in hemiparetic subjects, and whether such a reduction could be associated with a

decrease in stretch reflex excitability and an improvement in voluntary motor function. We compared the effects of 15 daily 60 min TENS treatments over a 3 week period, with those of placebo stimulation applied to the common peroneal nerve of the affected leg in similar groups of spastic hemiparetic subjects. Our test battery consisted of 5 measurements which assessed (1) clinical spasticity scores, (2) maximal H reflex to M response ratios, (3) vibratory inhibition of H reflex, (4) stretch reflexes, and (5) maximal voluntary isometric plantarflexion and dorsiflexion, in standing. In contrast to placebo stimulation which produced no significant effects, repeated applications of TENS over time decreased clinical spasticity (P less than 0.05), and increased vibratory inhibition of the soleus H reflex (P = 0.02) after 2 weeks. These changes occurred with a substantial improvement in voluntary dorsiflexing force up to 820%, but not plantarflexing force. They were followed by a reduction in the magnitude of stretch reflexes (P = 0.05) in the spastic ankle plantarflexor, concomitant with a decrease in the EMG co-contraction ratios after a further week of stimulation. Our results thus indicated that repeated applications of TENS can reduce clinical spasticity and improve control of reflex and motor functions in hemiparetic subjects. Furthermore, the underlying mechanisms may be due partly to an enhancement in presynaptic inhibition of the spastic plantarflexor, and partly to a possible "disinhibition" of descending voluntary commands to the paretic dorsiflexor motoneurons.

The effects of ipsilateral forearm movement and contralateral hand grasp on the spastic hand opened by electrical stimulation.
Lin C.
Neurorehabil Neural Repair. 2000;14(3):199-205.
Department of Neurology, National Cheng-Kung University Hospital, Tainan

The purpose of this study was to investigate the effects of ipsilateral arm movement and contralateral hand grasp on the spastic hand opened by open-loop electrical stimulation. The major problem of applying proper electrical stimulation is variable spasticity, the intensity of which changes with posture and movements of other parts of the body. Electrical stimulation was applied to extensor digitorum communis and ulnar nerve to open the affected hand. Different procedures were then used to assess the effects of moving the ipsilateral forearm and contracting the contralateral normal hand. Electrical stimulation opened the spastic hand in more than 95% of trials in all subjects, whether stimulation was applied before or after the movement of the forearm. Moving the ipsilateral forearm did have an effect on opening the hand, and making adjustment of stimulation intensities was necessary in all subjects. The stimulation opened the spastic hand during the contraction of the contralateral normal hand. Electrical stimulation could open the spastic hands most of the time, in the resence of ipsilateral forearm movement and contralateral normal hand contraction. If electrical stimulation was applied before the ipsilateral forearm was moved toward the target, stimulation intensities needed to be adjusted.

Neuromuscular electrical stimulation and dynamic bracing as a treatment for upper-extremity spasticity in children with cerebral palsy.
Scheker LR, Chesher SP, Ramirez S.
J Hand Surg [Br]. 1999 Apr;24(2):226-32.
Christine M. Kleinert Institute for Hand and Micro Surgery and the University of Louisville School of Medicine, Division of Plastic and Reconstructive Surgery, KY, USA.

We have investigated a therapeutic regimen using neuromuscular electrical stimulation (NMES) and dynamic bracing to assess their effectiveness in

reducing upper-extremity spasticity in children with cerebral palsy. Nineteen patients between 4 and 21 years of age with documented diagnoses of spastic cerebral palsy were treated. The patients included in the study followed a regimen of two 30-minute sessions of NMES of the antagonist extensors combined with dynamic orthotic traction during the day. A static brace was used at night. Spasticity of the wrist and fingers was assessed periodically using the Zancolli classification. Treatment ranged from 3 to 43 months. After treatment with electrical stimulation and dynamic bracing, all the patients moved up 1 to 3 levels in the Zancolli classification and showed a marked improvement in upper-extremity function. These results show that combining NMES and dynamic orthotic traction dramatically decreases spasticity of the upper extremity in young patients with cerebral palsy.

Neuromuscular electrical stimulation for the head-injured patient.
Baker LL, Parker K, Sanderson D.
Phys Ther. 1983 Dec;63(12):1967-74.
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.

Use of electrical stimulation in brain-injured patients: a case report.
Oostra K, Van Laere M, Scheirlinck B.
Brain Inj. 1997 Oct;11(10):761-4.
Rehabilitation Center, University Hospital, Gent, Belgium.

After failure of other therapeutic measures, electrical stimulation was applied to promote gait rehabilitation in a patient with severe brain injury and complete left hemiplegia. The favourable results reported in the literature were confirmed. Despite the long interval between injury and institution of electrical stimulation, independent ambulation was quickly restored.

The use of therapeutic electrical stimulation in the treatment of hemiplegic cerebral palsy.
Hazlewood ME, Brown JK, Rowe PJ, Salter PM.
Dev Med Child Neurol. 1994 Aug;36(8):661-73.
Department of Physiotherapy, Royal Hospital for Sick Children, Edinburgh.

The effect of electrical stimulation of the anterior tibial muscles of children with hemiplegic cerebral palsy was studied. 10 children received electrical stimulation, applied by their parents daily for an hour for 35 days; they were compared with 10 matched controls. Active and passive ranges of movement of the ankle, and knee and ankle motion during walking were measured before and after therapy using electrogoniometers. The results showed a significant increase in passive range of movement among children receiving electrical stimulation. Gait analysis of knee and ankle motion showed little change.

Functional electric stimulation in the reversal of conversion disorder paralysis.
Khalil TM, Abdel-Moty E, Asfour SS, Fishbain DA, Rosomoff RS, Rosomoff HL.
Arch Phys Med Rehabil. 1988 Jul;69(7):545-7.
Comprehensive Pain and Rehabilitation Center,
University of Miami, School of Medicine, Coral Gables, FL 33124.

Numerous reports have documented the usefulness of functional electric stimulation (FES) in restoring and/or improving the function of organically diseased or paralyzed muscles. There are few reports related to the use of FES in the treatment of conversion disorder paralysis of the hysterical type. This paper presents a case of hysterically paralyzed muscles where the patient received daily treatment with FES for two weeks. Electric current was applied to a weak quadriceps and to paralyzed tibialis anterior muscles. This electrotherapeutic modality was effective in improving the function of the quadriceps and in reversing the paralysis of the tibialis anterior muscles. The improvement in the muscles' functional abilities was documented through the use of quantitative measures of muscle strength as well as computerized analysis of EMG signals. The results showed that the administration of FES resulted in a dramatic increase in motor units recruitment, increased muscle strength, and improved voluntary muscle control.

Prognostic factors in the prediction of chronic wound healing by electrical stimulation.
Cukjati D, Robnik-Sikonja M, Rebersek S, Kononenko I, Miklavcic D.
Med Biol Eng Comput. 2001 Sep;39(5):542-50.
Faculty of Electrical Engineering, University of Ljubljana, Slovenia.

The aim of the study is to determine the effects of wound, patient and treatment attributes on the wound healing rate and to propose a system for wound healing rate prediction. Predicting the wound healing rate from the initial wound, patient and treatment data collected in a database of 300 chronic wounds is not possible. After considering weekly follow-ups, it was determined that the best prognostic factors are weekly follow-ups of the wound healing process, which alone were found to predict accurately the wound healing rate after a minimum follow-up period of four weeks (at least five measurements of wound area). After combining the follow-ups with wound, patient and treatment attributes, the minimum follow-up period was reduced to two weeks (at least three measurements of wound area). After a follow-up period of two weeks, it was possible to predict the wound healing rate of an independent test set of chronic wounds with a relative squared error of 0.347, and after three weeks, with a relative squared error of 0.181 (using regression trees with linear equations in its leaves). Regression trees with a relative squared error close to 0 produce better prediction than with an error closer to 1. Results show that the type of treatment is just one of many prognostic factors. Arranged in order of decreasing prediction capability, prognostic factors are: wound size, patient's age, elapsed time from wound appearance to the beginning of the treatment, width-to-length ratio, location and type of treatment. The data collected support former findings that the biphasic- and direct-current stimulation contributes to faster healing of chronic wounds. The model of wound healing dynamics aids the prediction of chronic wound healing rate, and hence helps with the formulation of appropriate treatment decisions.

Choosing an adjunctive therapy for the treatment of chronic wounds.
Houghton PE, Campbell KE.
Ostomy Wound Manage. 1999 Aug;45(8):43-52; quiz 53-4.

St. Joseph's Health Center, School of Physiotherapy, University of Western Ontario, London, Canada.

Adjunctive therapies such as ultrasound, laser, ultraviolet light, superficial heating, pulsed electromagnetic fields, and electrical stimulation have all been indicated in the treatment of chronic wounds. The purpose of this article is to outline the issues a healthcare professional must consider when choosing the best adjunctive therapy for a chronic wound. It summarizes the effects of therapeutic modalities on the wound healing process, analyzes the clinical research evidence, discusses practical considerations, and reviews indications, contraindications, precautions, and safety considerations. Finally, an algorithm is presented to help guide the clinician in selecting a modality. In summary, research evidence exists in the literature that suggests these adjunctive therapies can directly stimulate new tissue growth, augment wound tissue strength, improve local circulation and oxygenation, reduce edema, and/or inhibit bacterial growth. Electrical stimulation and ultrasound are the only therapeutic modalities that currently have sufficient clinical research evidence to support their use in the treatment of chronic wounds. Practical issues such as cost, time and training required, and patient and therapist safety concerns, will ultimately influence the selection of these modalities.

Effect of electrical stimulation on chronic wound healing: a meta-analysis.
Gardner SE, Frantz RA, Schmidt FL.
Wound Repair Regen. 1999 Nov-Dec;7(6):495-503.
Colleges of Nursing, The University of Iowa, Iowa City, IA 52242-7066, USA.

The purpose of this meta-analysis was to quantify the effect of electrical stimulation on chronic wound healing. Fifteen studies, which included 24 electrical stimulation samples and 15 control samples, were analyzed. The average rate of healing per week was calculated for the electrical stimulation and control samples. Ninety-five percentage confidence intervals were also calculated. The samples were then grouped by type of electrical stimulation device and chronic wound and reanalyzed. Rate of healing per week was 22% for electrical stimulation samples and 9% for control samples. The net effect of electrical stimulation was 13% per week, an increase of 144% over the control rate. The 95% confidence intervals of the electrical stimulation (18-26%) and control samples (3.8-14%) did not overlap. Electrical stimulation was most effective on pressure ulcers (net effect = 13%). Findings regarding the relative effectiveness of different types of electrical stimulation device were inconclusive. Although electrical stimulation produces a substantial improvement in the healing of chronic wounds, further research is needed to identify which electrical stimulation devices are most effective and which wounds respond best to this treatment.

A comparative study of the effect of ultrasound and electrostimulation on wound healing in rats.
Taskan I, Ozyazgan I, Tercan M, Kardas HY, Balkanli S, Saraymen R, Zorlu U
Plast Reconstr Surg. 1997 Sep;100(4):966-72.
Physical Therapy and Rehabilitation Center, Medical Faculty of Inonu University, Istanbul, Turkey.

A comparative study has been carried out to investigate the effects of electrical stimulation and ultrasound on wound healing. Eighty-four female rats were divided into four groups depending on the treatment received. The first group was given electrical stimulation of 300 microA direct current, 30 minutes daily, starting with negative polarity and then changed after 3 days of treatment. Group 2 received sham electrostimulation treatment. The

third group received 0.1 W/cm2 pulsed ultrasound using the moving applicator technique for 5 minutes a day. Group 4 received sham ultrasound treatment. A total of 7 days of treatment was given to all groups. Histopathologic and biochemical analyses on the fourth and seventh days and wound breaking strength on the twenty-fifth day were performed for all groups. By accelerating the inflammatory phase, electrical stimulation had progressed the proliferative phase of wound healing earlier than ultrasound had done. Both electrical stimulation and ultrasound have positive effects on proliferative phases, but electrical stimulation was superior to ultrasound at the maturation phase. There was no difference between the two experimental groups on the mast cell reduction effect. Although ultrasound treatment may seem to be efficient in terms of time, when the effects of electrical stimulation and ultrasound on wound healing with the methods employed in our study are considered, it is concluded that electrical stimulation is a means of treatment superior to ultrasound in wound healing.

Effects of electrical stimulation on wound healing in patients with diabetic ulcers.
Baker LL, Chambers R, DeMuth SK, Villar F.
Diabetes Care. 1997 Mar;20(3):405-12.
Department of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles 90033,

OBJECTIVE: To evaluate the effects of two stimulation waveforms on healing rates in patients with diabetes and open ulcers. The hypothesis was that stimulus waveforms with minimal polar characteristics would provide significant healing for this patient sample. RESEARCH DESIGN AND METHODS: This was a prospective study that enrolled 80 patients with open ulcers. Patients received stimulation with either an asymmetric biphasic (A) or symmetric biphasic (B) square-wave pulse. Amplitudes were set to activate intact peripheral nerves in the skin. Two other groups received either very low levels of stimulation current (MC), or no electrical stimulation (C). When combined these groups were referred to as the control group. Treatment was carried out daily until the wound healed, the patient withdrew from the study, or the physician changed the overall wound management program. Average healing rates were calculated from weekly measures of the wound perimeter and were used for statistical comparison through a one-way analysis of variance. RESULTS: Stimulation with the A protocol significantly increased the healing rate, enhancing healing by nearly 60% over the control rate of healing. Stimulation with the B protocol did not increase the healing rate when compared with control subjects. CONCLUSIONS: Electrical stimulation, given daily with a short pulsed, asymmetric biphasic waveform, was effective for enhancement of healing rates for patients with diabetes and open ulcers.

Promotion of wound healing with electrical stimulation.
Kloth LC, McCulloch JM.
Adv Wound Care. 1996 Sep-Oct;9(5):42-5.
Program of Physical Therapy, Marquette University, Milwaukee, Wis, USA.

Clinicians involved in the conservative care of chronic wounds have many treatment interventions from which to choose, including debridement/irrigation, dressings, pressure-relieving devices, hyperbaric or topically applied oxygen, whirlpool/pulsed lavage, ultrasound, topical antibiotics, and cytokine growth factors. All except the last two interventions are physical treatments that create a wound-tissue environment conducive to healing. Unfortunately, many chronic wounds heal very slowly, do not heal, or worsen despite the best efforts of caregivers to promote tissue

repair. An intervention commonly used to treat chronic wounds, especially by physical therapists, is electrical stimulation (ES). The rationale for use of this method is based on the fact that the human body has an endogenous bioelectric system that enhances healing of bone fractures and soft-tissue wounds. When the body's endogenous bioelectric system fails and cannot contribute to wound repair processes, therapeutic levels of electrical current may be delivered into the wound tissue from an external source. The external current may serve to mimic the failed natural bioelectric currents so that wound healing can proceed. Certain chemotaxic factors found in wound substrates contribute to tissue repair processes by attracting cells into the wound environment. Neutrophil, macrophage, fibroblast, and epidermal cells involved in wound repair carry either a positive or negative charge. When these cells are needed to contribute to autolysis, granulation tissue formation, anti-inflammatory activities, or epidermal resurfacing, ES may facilitate galvanotaxic attraction of these cells into the wound tissue and thereby accelerate healing.

Physical modalities in wound management: UVC, therapeutic heating and electrical stimulation.
Kloth LC.
Ostomy Wound Manage. 1995 Jun;41(5):18-20, 22-4, 26-7.

In spite of efforts to create an optimum wound environment for healing, there are times that a wound may not heal, may heal very slowly, or may worsen. In these cases, a series of treatments with an appropriate physical agent can be added to the patient's care plan to augment tissue reparative processes. Three modalities that have received support in the literature for use in wound healing are ultraviolet "C" radiation (UVC), therapeutic heating, and electrical stimulation. Treatment goals for UVC are hyperplasia and enhanced re-epithelialization or desquamation of the leading edge of periulcer epidermal cells, granulation tissue formation, sloughing of necrotic tissue, and bactericidal effects. Treatment goals for therapeutic heating are increased blood perfusion with subsequent increased delivery of oxygen to the tissues (avoiding the dessication of wound tissues). The treatment goal for electrical stimulation is to attract negatively or positively charged cells into the wound area, such as neutrophils, macrophages, epidermal cells and fibroblasts that in turn will contribute to wound healing processes by way of their individual cellular activities.

Experimental wound healing with electrical stimulation.
Reger SI, Hyodo A, Negami S, Kambic HE, Sahgal V
Title Abbreviation: Artif Organs.
1999 May; 23(5):460-2.
Department of Physical Medicine and Rehabilitation, The Cleveland Clinic Foundation, Ohio 44195, USA.

The effect of alternating current (AC) and direct current (DC) stimulation was studied on experimental pressure ulcer healing in a new monoplegic pig model. The study was conducted in 30 healthy young Hanford minipigs. The rate of wound healing, histology, vascularization, collagen formation, microbiology, perfusion, and the mechanical strength of the healed wounds were studied. Normal pigskin was compared to denervated control and denervated AC and DC stimulated healed skin. Hind limb denervation was by right unilateral extradural rhizotomies from the L2 to S1 nerve roots. Reproducible uniformly controlled Stage III or higher tissue ulcers were created. When compared to the control wounds, both the AC and DC stimulated wounds showed reduced healing time and increased perfusion in the early phases of healing. DC

stimulation reduced the wound area more rapidly than AC, but AC stimulation reduced the wound volume more rapidly than DC. The electrical stimulation did not reduce the strength of the healing wounds below those of the nonstimulated controls. The applied current appears to orient new collagen formation even in the absence of neural influences.

Electric muscle stimulation for pressure sore prevention: tissue shape variation.
Levine SP Kett RL Cederna PS Brooks SV
Arch Phys Med Rehabil (1990 Mar) 71(3):210-5

This study measured changes in tissue shape and deformation at the seating interface produced by electric muscle stimulation (EMS) of the gluteus maximus. The purpose of the study was to investigate the application of EMS for pressure sore prevention. Limitations of pressure measurements for analysis of load distribution are discussed and a rationale developed for using tissue shape and deformation to further characterize the seating interface. Ultrasonic imaging of the seating interface is described under three conditions: buttocks suspended, external load applied with no EMS, and external load applied with bilateral EMS of the buttocks. Results show that low level stimulation of the gluteus maximus produces substantial changes in the shape of the loaded buttocks and an external contour more nearly shaped like the suspended buttocks. It is concluded that EMS produces buttock tissue undulation and shape reconfiguration which may assist in preventing pressure sores over the seating surface.

Adjuvant therapy for ulcer care.
Frantz RA
Clin Geriatr Med (1997 Aug) 13(3):553-64

Adjuvant therapies, specifically electrotherapy, hyperbaric oxygen, ultrasound, and hydrotherapy, are considered increasingly for use with conventional local wound care to support healing of pressure ulcers. This article describes the characteristics of these modalities, their physiologic effects on the healing process, and the research to evaluate their efficacy.

Effects of electrical stimulation on wound healing in patients with diabetic ulcers.
Baker LL Chambers R DeMuth SK Villar F
Diabetes Care (1997 Mar) 20(3):405-12

OBJECTIVE: To evaluate the effects of two stimulation waveforms on healing rates in patients with diabetes and open ulcers. The hypothesis was that stimulus waveforms with minimal polar characteristics would provide significant healing for this patient sample. RESEARCH DESIGN AND METHODS: This was a prospective study that enrolled 80 patients with open ulcers. Patients received stimulation with either an asymmetric biphasic (A) or symmetric biphasic (B) square-wave pulse. Amplitudes were set to activate intact peripheral nerves in the skin. Two other groups received either very low levels of stimulation current (MC), or no electrical stimulation (C). When combined these groups were referred to as the control group. Treatment was carried out daily until the wound healed, the patient withdrew from the study, or the physician changed the overall wound management program. Average healing rates were calculated from weekly measures of the wound perimeter and were used for statistical comparison through a one-way analysis of variance. RESULTS: Stimulation with the A protocol significantly increased the healing rate, enhancing healing by nearly 60% over the control rate of healing.

Stimulation with the B protocol did not increase the healing rate when compared with control subjects. CONCLUSIONS: Electrical stimulation, given daily with a short pulsed, asymmetric biphasic waveform, was effective for enhancement of healing rates for patients with diabetes and open ulcers.

The benefit of electrical stimulation to enhance perfusion in persons with diabetes mellitus.
Peters EJ Armstrong DG Wunderlich RP Bosma J Stacpoole-Shea S Lavery LA
J Foot Ankle Surg (1998 Sep-Oct) 37(5):396-400; discussion 447-8

The purpose of this study was to evaluate the effect of galvanic electrical stimulation on vascular perfusion in diabetic patients. Nineteen subjects with diabetes were enrolled. Eleven subjects (57.9%) were diagnosed with impaired peripheral perfusion based upon their initial transcutaneous oximetry values (< 40 mm Hg). The subjects were studied over a 2-day period. On the 1st day, one foot was electrically stimulated for four 60-minute periods by an external electrical stimulation device. Vascular perfusion of both feet was assessed before and after the sessions of electrical stimulation. On the 2nd day, no electrical stimulation was applied and noninvasive vascular measurements were repeated. For the 1st hour, transcutaneous oxygen pressure was measured continuously during stimulation at the lateral aspect of the leg. Subsequently, perfusion between the periods of stimulation was measured on the dorsum of the foot with both transcutaneous oximetry and laser Doppler flowmetry after each stimulation period. In the group with impaired peripheral perfusion, a significant rise in tissue oxygenation as compared to the control measurements was measured during the first 5 minutes of stimulation ($p < .040$). For those without vascular disease (TcpO2 > 40 mm Hg) however, there was not a significant increase compared to baseline ($p = .280$). After the periods of stimulation, the stimulated feet did not show any higher perfusion levels than the control feet. Patterns in perfusion during the day, as measured by laser Doppler flowmetry, were similar in the tested feet and in the controls. These data suggest that external subsensory electrical stimulation induces a transient rise in skin perfusion in persons with diabetes and impaired peripheral perfusion.

Treatment of chronic wounds by means of electric and electromagnetic fields. Part 2. Value of FES parameters for pressure sore treatment.
Stefanovska A Vodovnik L Benko H Turk R
Med Biol Eng Comput (1993 May) 31(3):213-20

Subjects with spinal cord injury are often distressed by pressure sores, which usually appear after prolonged pressure (wheelchair, bed) across the soft tissue which has already lost sensibility and has diminished microcirculation. The healing ability and its dynamics depend on the state of the subject's overall health. Consequently, evaluation of a particular treatment requires careful consideration of as many as possible of the parameters relevant to healing and an adequate criterion for assessing the state of the pressure sore. Bearing in mind these two circumstances, the results of a multicentre clinical study are analysed. The aim of the study was to test two hypotheses: first that healing is faster when sores are also treated by electric currents (ECs) (in addition to conventional treatment); and secondly that there exist differences in the efficiency of the treatment if direct or low-frequency pulsed currents (FES parameters) are applied. The data analysed show that pressure sores are likely to heal twice as fast when treated with low-frequency pulsed currents. EC seems to improve the healing rate in cases where the natural healing mechanisms of the body are not sufficient (chronic wounds, older subjects).

Reduction of seating pressure using FES in patients with spinal cord injury. A preliminary report.
Ferguson AC Keating JF Delargy MA Andrews BJ
Paraplegia (1992 Jul) 30(7):474-8

The aim of this study was to investigate the use of functional electrical stimulation (FES) as a means of pressure sore prevention in seated spinal cord injured (SCI) subjects. Nine SCI subjects took part in tests in which electrical stimulation was applied to the quadriceps with the lower legs restrained. Ischial pressures were measured during periods of quiet sitting and FES application. A strain gauged lever arm was used to measure the knee moment during quadriceps stimulation. The average pressure drop at the right and left buttocks was 44 mmHg and 27 mmHg respectively. In general the greatest reductions occurred in subjects with larger knee moments; however, there was no direct relationship between the pressure reduction obtained and the quadriceps strength. This form of FES may be useful as a prophylactic aid in the management of pressure sores in SCI subjects.

Chronic dermal ulcer healing enhanced with monophasic pulsed electrical stimulation
Feedar JA Kloth LC Gentzkow GD
Phys Ther (1991 Sep) 71(9):639-49

The purposes of this randomized, double-blind, multicenter study were to compare healing of chronic dermal ulcers treated with pulsed electrical stimulation with healing of similar wounds treated with sham electrical stimulation and to evaluate patient tolerance to the therapeutic protocol. Forty-seven patients, aged 29 to 91 years, with 50 stage II, III, and IV ulcers were randomly assigned to either a treatment group (n = 26) or a control (sham treatment) group (n = 24). Treated wounds received 30 minutes of pulsed cathodal electrical stimulation twice daily at a pulse frequency of 128 pulses per second (pps) and a peak amplitude of 29.2 mA if the wound contained necrotic tissue or any drainage that was not serosanguinous. A saline-moistened nontreatment electrode was applied 30.5 cm (12 in) cephalad from the wound. This protocol was continued for 3 days after the wound was debrided or exhibited serosanguinous drainage. Thereafter, the polarity of the treatment electrode on the wound was changed every 3 days until the wound progressed to a stage II classification. The pulse frequency was then reduced to 64 pps, and the treatment electrode polarity was changed daily until the wound was healed. Patients in the control group were treated with the same protocol, except they received sham electrical stimulation. After 4 weeks, wounds in the treatment and control groups were 44% and 67% of their initial size, respectively. The healing rates per week for the treatment and control groups were 14% and 8.25%, respectively. The results of this study indicate that pulsed electrical stimulation has a beneficial effect on healing stage II, III, and IV chronic dermal ulcers.

Effect of electrical stimulation on foot skin perfusion in persons with or at risk for diabetic foot ulcers.
Gilcreast DM Stotts NA Froelicher ES Baker LL Moss KM
Wound Repair Regen (1998 Sep-Oct) 6(5):434-41

The failure of foot wounds to heal results in 54,000 people with diabetes having to undergo extremity amputations annually. Therefore, treatment is needed to speed healing in people with diabetes in order to reduce the need for amputation. This study tested the effect of high-voltage pulsed current

on foot blood flow in human beings who are at risk for diabetic foot ulcers. Neuropathy, vascular disease, Wagner Class, glucose, gender, ethnicity, and age were measured. A sample of 132 subjects was tested using a repeated-measures design. A baseline transcutaneous oxygen level was obtained; stimulation was applied, and transcutaneous oxygen measurements were recorded at 30- and 60- minute time intervals. The grouped foot transcutaneous oxygen levels decreased (F = 5.66, p =. 0039) following electrical stimulation. Analysis of variance (Scheffe, p <.05) showed that initial transcutaneous oxygen was significantly higher than subsequent readings. However, oxygen response was distributed bimodally: 35 (27%) subjects showed increased transcutaneous oxygen (mean 14.8 mm Hg), and 97 (73%) experienced a decreased transcutaneous oxygen reading (mean 12.2 mm Hg). Logistic regression analysis did not explain these differences. Although this treatment appears to increase blood flow in a subset of patients, further study is needed to identify probable mechanisms for this response.

Biofeedback and functional electric stimulation in stroke Rehabilitation.
Cozean CD Pease WS Hubbell SL
Arch Phys Med Rehabil (1988 Jun) 69(6):401-5

The study examined the efficacy of functional electric stimulation (FES) and biofeedback (BFB) treatment of gait dysfunction in patients with hemiplegia after stroke. These two therapeutic modalities were tested alone and in combination in a prospective, controlled, randomized trial. The authors hypothesized that in concurrent use, these two modalities would complement one another. Thirty-six hemiplegic patients undergoing rehabilitation after stroke were accepted for study and randomized into four groups to receive either control, FES, BFB, or combined therapies. Each patient received 30 minutes of treatment three times per week for six weeks, in addition to their general rehabilitation program. Quantitative gait analysis was performed biweekly on each subject during the experimental therapy and for four weeks afterward. Thirty-two subjects completed the study. Combined therapy with BFB and FES resulted in improvements in both knee and ankle minimum flexion angles during swing phase that were statistically significant with p = 0.05 and p = 0.02, respectively. Velocity of gait, cycle time, and symmetry of stance phases also improved. The length of time elapsed since the stroke did not prove to be a significant factor.

Reduction of seating pressure using FES in patients with spinal cord injury. A preliminary report.
Ferguson AC Keating JF Delargy MA Andrews BJ
Paraplegia (1992 Jul) 30(7):474-8

The aim of this study was to investigate the use of functional electrical stimulation (FES) as a means of pressure sore prevention in seated spinal cord injured (SCI) subjects. Nine SCI subjects took part in tests in which electrical stimulation was applied to the quadriceps with the lower legs restrained. Ischial pressures were measured during periods of quiet sitting and FES application. A strain gauged lever arm was used to measure the knee moment during quadriceps stimulation. The average pressure drop at the right and left buttocks was 44 mmHg and 27 mmHg respectively. In general the greatest reductions occurred in subjects with larger knee moments; however, there was no direct relationship between the pressure reduction obtained and the quadriceps strength. This form of FES may be useful as a prophylactic aid in the management of pressure sores in SCI subjects.

Relative changes in blood flow with functional electrical stimulation during exercise of the paralyzed lower limbs.
Phillips W Burkett LN Munro R Davis M Pomeroy K
Paraplegia (1995 Feb) 33(2):90-3

Eight spinal cord injured (SCI) patients performed three sets of exercise with two conditions, 60% and 80% of VO2peak, with an arm crank ergometer. Functional neuromuscular stimulation was used to induce static leg contractions in two of the above sets of exercise. The three exercise sets were performed with no functional neuromuscular stimulation (NOS); with functional neuromuscular stimulation at 40 milliamperes; and with functional neuromuscular stimulation at 80 milliamperes (HIS). The lower limb blood flow was estimated by a photoelectric plethysmograph. Results showed that the lower limb blood flow was consistently reduced across both functional neuromuscular stimulation levels (17.4% from NOS to LOS; 13.8% from LOS to HIS; and 28.8% from NOS to HIS), and work loads (15.3% from rest to 60% VO2peak; 38.0% from 60% VO2peak to 80% VO2peak; and 47.5% from rest to 80% VO2peak). Rate-pressure product was decreased by 8.3% between NOS and HIS at 60% VO2peak (15.7 +/- 3.4 to 14.4 +/- 3.8), by 6.8% between NOS and HIS at 80% VO2peak (18.9 +/- 53 to 17.6 +/- 4.8), and by 12.4% between LOS and HIS at 80% VO2peak (20.1 +/- 6.7 to 17.6 +/- 4.8). These data indicate that in SCI (a) functional neuromuscular stimulation-induced contractions of the lower limb muscles can increase blood flow and thus reduce venous blood pooling in the paralyzed muscles, and (b) such improvements are associated with a reduced rate pressure product.(ABSTRACT TRUNCATED AT 250 WORDS)

Promotion of wound healing with electrical stimulation.
Kloth LC McCulloch JM
Adv Wound Care (1996 Sep-Oct) 9(5):42-5

Clinicians involved in the conservative care of chronic wounds have many treatment interventions from which to choose, including debridement/irrigation, dressings, pressure-relieving devices, hyperbaric or topically applied oxygen, whirlpool/pulsed lavage, ultrasound, topical antibiotics, and cytokine growth factors. All except the last two interventions are physical treatments that create a wound-tissue environment conducive to healing. Unfortunately, many chronic wounds heal very slowly, do not heal, or worsen despite the best efforts of caregivers to promote tissue repair. An intervention commonly used to treat chronic wounds, especially by physical therapists, is electrical stimulation (ES). The rationale for use of this method is based on the fact that the human body has an endogenous bioelectric system that enhances healing of bone fractures and soft-tissue wounds. When the body's endogenous bioelectric system fails and cannot contribute to wound repair processes, therapeutic levels of electrical current may be delivered into the wound tissue from an external source. The external current may serve to mimic the failed natural bioelectric currents so that wound healing can proceed. Certain chemotaxic factors found in wound substrates contribute to tissue repair processes by attracting cells into the wound environment. Neutrophil, macrophage, fibroblast, and epidermal cells involved in wound repair carry either a positive or negative charge. When these cells are needed to contribute to autolysis, granulation tissue formation, anti-inflammatory activities, or epidermal resurfacing, ES may facilitate galvanotaxic attraction of these cells into the wound tissue and thereby accelerate healing.

Electrical nerve stimulation improves healing of diabetic ulcers.
Lundeberg TC Eriksson SV Malm M

Ann Plast Surg (1992 Oct) 29(4):328-31

A controlled study of the effects of electrical nerve stimulation (ENS) was performed in conjunction with a standard treatment for healing chronic diabetic ulcers on 64 patients divided randomly into two groups. All patients received standard treatment (paste-impregnated bandage and a self-adhesive elastic bandage) plus placebo ENS or ENS (alternating constant current; frequency, 80 Hz; pulse width, 1 msec; intensity-evoking strong paresthesias) for 20 minutes twice daily for 12 weeks. Comparison of percentages of healed ulcer area and the number of healed ulcers was made after 2, 4, 6, 8, and 12 weeks. There were significant differences ($p < 0.05$) in both ulcer area and healed ulcers in the ENS group compared with the placebo group after 12 weeks of treatment. The results of the present study support the use of ENS in diabetic ulcers. ENS is easy to apply and can be used by the patient at home following instructions from a medical doctor or a therapist experienced in electrical stimulation and the treatment of ulcers. Additional studies are needed to identify the mechanisms involved in the promotion of ulcer healing with electrical stimulation and to determine the stimulus variables that most efficaciously accelerate tissue repair.

Effects of electrical stimulation on wound healing in patients with diabetic ulcers.
Baker LL Chambers R DeMuth SK Villar F
Diabetes Care (1997 Mar) 20(3):405-12

OBJECTIVE: To evaluate the effects of two stimulation waveforms on healing rates in patients with diabetes and open ulcers. The hypothesis was that stimulus waveforms with minimal polar characteristics would provide significant healing for this patient sample. RESEARCH DESIGN AND METHODS: This was a prospective study that enrolled 80 patients with open ulcers. Patients received stimulation with either an asymmetric biphasic (A) or symmetric biphasic (B) square-wave pulse. Amplitudes were set to activate intact peripheral nerves in the skin. Two other groups received either very low levels of stimulation current (MC), or no electrical stimulation (C). When combined these groups were referred to as the control group. Treatment was carried out daily until the wound healed, the patient withdrew from the study, or the physician changed the overall wound management program. Average healing rates were calculated from weekly measures of the wound perimeter and were used for statistical comparison through a one-way analysis of variance. RESULTS: Stimulation with the A protocol significantly increased the healing rate, enhancing healing by nearly 60% over the control rate of healing. Stimulation with the B protocol did not increase the healing rate when compared with control subjects. CONCLUSIONS: Electrical stimulation, given daily with a short pulsed, asymmetric biphasic waveform, was effective for enhancement of healing rates for patients with diabetes and open ulcers.

Electrical stimulation to heal dermal wounds.
Gentzkow GD
J Dermatol Surg Oncol (1993 Aug) 19(8):753-8

BACKGROUND. Numerous human and animal efficacy studies have demonstrated that electrical stimulation of the correct charge, density and total energy causes dramatically improved healing of dermal wounds. The investigations of biological actions (in vitro, animal, and human) demonstrate several effects that go a long way to explaining why electrical stimulation works. OBJECTIVE. To discuss recent research and advances in electrical stimulation of wound healing. RESULTS. Based on the latest scientific understanding of the wound healing process, one would expect a beneficial outcome from a therapy what

decreases edema, debrides necrotic tissue, attracts neutrophils and macrophages, stimulates receptor sites for growth factors, stimulates growth of fibroblasts and granulation tissue, increases blood flow, stimulates neurite growth, induces epidermal cell migration, prevents post-ischemic oxygen radical-mediated damage, inhibits bacteria, and reduces numbers of mast cells. CONCLUSION. Taken together, the efficacy studies and the "mechanism of action" studies provide compelling, scientific evidence that electrical stimulation is safe and effective for promoting the healing of dermal wounds.