

Electrical Stimulation In Spinal Cord Injury

Problems To Be Addressed In The First Weeks And Months After Spinal Cord Injury

During this time period, electrical stimulation [ES] may be suggested by the medical care team. Each individual patient must be evaluated to determine if there are any contraindications or precautions in the use of ES. SCI candidates for ES must have peripheral nerve supply, or an intact reflex arc, to the muscles to be stimulated. If the patient is a candidate, ES may be incorporated into daily therapy protocols and it may be a part of the patient's 24 hour per day regimen. Each application of ES will be designed to accomplish a specific goal in terms of prevention of a complication or accomplishment of a functional goal along the road to recovery.

Prevention Of Deep Venous Thrombosis

During periods of immobilization or paralysis, it is important to continue to contract the limb muscles to move the venous blood back to the heart and to prevent pooling of the blood. Goals of treatment during this period will include the prevention of deep venous thrombosis [DVT]. Pooling of the blood in the leg, or calf, is a particular problem because the blood can clot. If portions of the clot break off, they can travel along the venous pathway and lodge in the circulatory system and stop blood flow to the lungs or other organs. ES of the calf muscles has been shown to be effective in preventing DVT in a variety of patient groups. It has been reported that the ES induced muscle contraction of the calf muscles significantly improves venous drainage in the leg and that ES increases plasma fibrinolytic activity, or reduces the potential for clotting, in the spinal cord injury patients studied. In some studies, ES was used successfully in combination with low-dose heparin therapy [or anti-coagulant] therapy.

Although some investigators have reported limited effectiveness for the patient who is at high risk for DVT, ES can provide a simple means of contracting the leg muscles when the patient cannot do it for himself. It is important that the stimulation characteristics be adjusted to provide maximal comfort and minimal muscle fatigue during the "calf pumping" exercise. It is essential that all caregivers, medical or family, understand that the stimulation is to be used frequently throughout the day and night during the period of paralysis or immobilization. For example, the stimulator may be programmed to turn on and provide 10 to 15 minutes of exercise each hour. This intervention can be carried out in a hospital or home setting at minimal cost with a variety of inexpensive stimulators.

Prevention And Management Of Pressure Sores

Electrical stimulation of the muscle groups that provide the most support or cushion for the bony structures during supine positioning and sitting can be an effective means of reducing the risk of pressure sore development. It may be combined with frequent position changes, mattresses and cushions to effectively distribute pressures, custom wheelchair dimensions and other methods of pressure sore prevention. Regular skin inspection must be continued despite the protocol and the patient must stay off any areas of reddened skin, if they appear, until the skin is no longer pink.

Once a pressure sore has developed, electrical stimulation may be added to pressure relief efforts and meticulous wound care. The success of ES protocols in wound healing have varied according to diagnosis, depth of the lesion and severity of metabolic compromise, but the results have been rewarding, as well as statistically significant, in the spinal injury patient population. Successful protocols have included daily stimulation for a total time of two or more

hours. Some investigators have employed a very low intensity direct current. Others have used a pulsatile current and created some muscle contraction in the area of the pressure sore. Electrodes may be placed adjacent to the wound or one of the electrodes may be placed in the wound. In the latter case, an electroconductive dressing is used as the electrode.

It must be recognized that not all spinal cord injured patients are candidates for ES to augment their wound healing. Tests must be performed to determine if there is a larger area of infection under the skin and if the infection has a pathway to other organs or to a joint. It is important to determine if there is infection of the underlying bone, or osteomyelitis. Surgical intervention may be necessary to clean the area and to graft muscle and skin to cover the bony prominences [ie a myocutaneous rotational flap graft]. Electrical stimulation may be of value prior to such surgery for the purpose of reducing spasticity. If the spasticity can be modulated before surgery, it may not be necessary to cut nerves, or do a neurectomy, to keep the spasticity from interfering with post-operative healing.

After wound closure, the mechanical integrity of the skin will not be the same as the original model and it will be essential to continue routine skin checks and to obtain custom seating devices to relieve pressure over bony areas.

Ventilatory Assistance

Mechanical movement of the chest and abdomen along with electrical stimulation of muscles to assist breathing dates back to the 1950's when these techniques were applied to polio and to some spinal cord injury patients. ES of the abdominal muscles was used, for instance, to compress the abdomen and assist in expiration and cough. There are many small, economical stimulators available today that may be employed to stimulate the abdominal muscles and assist with cough force in the effort to minimize respiratory infections.

Since the 1960's, many high quadriplegics have benefited from phrenic nerve stimulation or diaphragmatic pacing. Fully implanted ES systems can free the quadriplegic individual from a respirator and permit easier mobility in the community. As in all spinal cord applications, it must be emphasized that the phrenic nerves and the diaphragm must be intact and the lungs must be healthy.

Some research investigators are exploring ES of the thoracic spinal cord to activate the intercostal muscles. This approach would not free the respirator dependent patient but it appears to increase the amount of air inspired and improve other parameters of pulmonary function for the patient who is at risk for respiratory infection.

Encouragement Of The Return Of Voluntary Movement

After spinal cord injury, every attempt is made to help the patient regain control of weak or paralyzed muscles. ES may be incorporated into a variety of therapeutic strategies to enhance movement or muscle contraction. In the very early weeks, there is no way to predict if there is any potential to regain movement [unless there has been a complete transection of the cord]. After 3 or 4 weeks, it is possible to do various electrical diagnostic tests to determine if any of the nerve supply between the cord and the muscles of interest has been damaged, and to determine if there is any conduction of sensory or motor nerve impulses between the brain and the cord below the zone of spinal cord injury. If there is complete loss of the peripheral nerve to the muscles as a result of the death of motor nerve cells in the cord, recovery cannot occur and electrical stimulation cannot help regain control. If there is a partial loss of the

peripheral nerve, the remaining nerve going into the muscle[s] will adopt a number of the orphaned muscle fibers during the next six months. At the end of the six months, it will be possible to set realistic goals for muscle strengthening and functional activities such as walking. Rehabilitation dollars spent on strengthening of muscle with expectations of improvement in walking, for example, cannot be expected to be successful. Only after the muscle has regained a full nerve supply will strengthening be a reasonable goal. If there is no peripheral nerve damage, recovery depends upon the extent of damage to the pathways in the spinal cord and it is difficult to predict when, or if, voluntary control will return or improve. In this situation, immediate use of ES may offer a sensory cue in addition to assisting with joint range of motion exercise.

When ES is appropriate to encourage muscle activity, it offers a sensory cue which may increase the patient's awareness of their muscles and joints, encourage muscle recruitment and give feedback about standing posture and distribution of body weight on the feet. ES may be used to contract the muscles of interest so the patient can exercise with the stimulation. It is important for the patient to use ES along with other therapeutic measures and to have access to the stimulation around the clock, as prescribed. These activities may later be carried into functional tasks such as using the hand or standing, shifting weight from one leg to the other, and walking.

The functional applications of ES during this early rehabilitation period require the use of a small, wearable ES system that can be programmed and triggered to meet the changing needs of the recovering patient. There are a number of relatively inexpensive ES devices that could be employed. Although ES is effectively integrated with clinical therapy visits, a 24 hour per day ES protocol is essential for optimal recovery of voluntary movement.

Reduction Of A Subluxing, And Possibly Painful, Shoulder

A subluxing, or dislocating shoulder may be a problem in the high quadriplegic. When there is peripheral nerve supply to the critical shoulder muscles [such as the supraspinatus muscle which is supplied by the C5 and C6 spinal nerves], the goal of intervention is to minimize stretching of the shoulder joint capsule and structures of the shoulder, to prevent pain if there is sensation in the shoulder and if there is a possibility of recovery, to encourage the return of voluntary muscle activity about the shoulder. A shoulder sling may support the upper limb to some extent, but it does not replace the normal shoulder alignment. ES can reduce the shoulder and maintain that reduction for as many hours per day as needed and it may be used in conjunction with mobile arm supports for table top activities.

A simple ES device with skin electrodes can be extremely effective. The stimulation characteristics will need to be adjusted by a therapist in order to assure the effectiveness of the early ES protocol and to accomplish the goal of almost continual ES during the day to maintain shoulder alignment. ES may be used for sleeping, if pain is a problem at night.

This application is extremely economical and can be carried out at home with stimulation characteristic modification at the appropriate therapy visits.

In the future, shoulder subluxation may be managed with implanted ES devices in patients who do not recover voluntary control of the shoulder. Clinical investigation of the use of implanted electrodes for shoulder subluxation in the first few weeks after injury is currently in progress.

Prevention Of Joint Contractures

ES may be used to prevent or to treat joint contractures. Although the chance of correcting a joint contracture is greatest when the problem is of recent onset, various investigators have reported significant improvements in long-standing joint limitations. ES may be used in conjunction with specific exercise protocols [including splinting or bracing] before and after surgical intervention to correct deformities. The optimal use of ES would include early intervention and prevention of loss of joint motion.

It is critical to the success of range of motion [ROM] protocols to use ES several times each day. For any ROM program, the exercise must be done regularly during the day or night to regain motion. When the body segment to be moved is relatively small [ie fingers, wrist or ankle], the muscle pull created by ES alone may accomplish the goal. When the body segments are larger, at the knee or hip for example, ES may assist the patient in exercising to the end of their range. In the case of complete paralysis, ES must be combined with appropriate positioning protocols for ROM exercise. Most home programs have been accomplished with skin electrodes and inexpensive stimulators.

The reports of investigators using implanted ES systems at the hip are promising and implanted ES devices may be used to correct hip contractures in the future.

It is extremely important to recognize that the reduction of spasticity significantly influences the recognition of any residual voluntary muscle control and contributes to the success of prevention or correction of joint contractures.

Maintenance Of Bone Mineral Density

Despite research efforts to prevent the loss of bone mineral density after complete SCI, there is no proven way to accomplish this goal. In the future, a combination of ES and medications may prove effective. Some investigators have reported that the loss of bone mineral density, or osteopenia, can be partially reduced by ES and resistive exercise in SCI. It is important to consider the change in the rate of bone loss over time in the months and years after SCI. Because the rate of bone loss is greatest in the first 6 months after SCI and more gradual in the ensuing years, it is difficult to estimate expected bone loss in a group of subjects who were injured at different times. In order to adequately assess the effectiveness of ES on maintenance of bone mineral density, it is necessary to study SCI individuals over time.

Management Of Involuntary Muscle Activity [Or Spasticity]

The use of ES to manage spasticity [or involuntary muscle contraction because of increased stretch reflex sensitivity] dates back to the 1700's, and there is a wealth of literature related to ES and spasticity in the last 60 years. Not everyone may benefit from ES to reduce spasticity, but the majority of spinal cord injury patients have been relieved of pain and movement restriction when their spasticity was reduced. When ES alone is not sufficient to reduce interfering spasticity, it may be combined with medications.

A number of ES protocols with skin electrodes have been studied. All of these protocols would point to the efficacy of a home program for optimal success. The use of a sensory level stimulus intensity over the spastic muscles, or over areas of skin that receive a similar nerve

supply as the spastic muscles, has significantly reduced spasticity during clinical tests and during everyday activities. The use of skin electrodes to train muscles, or to contract muscles for exercise, has resulted in less spasticity and improved function. When electrical stimulation is used regularly in other parts of the body, for example to control the hand, spasticity has been reduced in the lower limbs.

It is important to remember that the maximum benefit of ES in the reduction of spasticity may not be realized until ES has been used for 1-2 hours per day for 1-3 months. It is equally important to realize that the reduction of spasticity will allow improved voluntary muscle control, if it exists, and increased joint range of motion. Procedures that paralyze muscle, such as a chemical nerve block or nerve resection may reduce spasticity, but they result in a weaker or a paralyzed muscle. ES acts to reduce interfering spasticity and unmask existing volitional control without weakening the muscle.

The specific physiological mechanisms of spasticity modulation are not well understood, but there is some consensus regarding the possible mechanisms. The side effects of ES for spasticity are minimal. If spasticity is made worse on the initial treatments, the effect will subside within 1-2 hours. If this is the case, a preliminary trial of low intensity, or sensory level electrical stimulation is indicated. If the patient is using their spasticity to help them initiate movement or to stabilize a joint, then the reduction of spasticity may make them temporarily less capable. So, it is important to utilize the expertise of a therapist who can evaluate the effects of ES on spasticity and provide an ES training protocol to improve muscle performance and provide suppression of spasticity over time.

Previous research with implanted ES systems [on the spinal cord or in the brain] has revealed a reduction in spasticity and an improvement in voluntary control. These procedures are not routinely available to clinical patients at this time. It is of interest that researchers using spinal cord stimulation to reduce pain are also observing reductions in spasticity in their stroke and spinal cord patients.

Recipients of neural prosthetic ES systems for hand function or assistance in walking [ie stimulation of peripheral nerve for functional activities] report that interfering spasticity throughout their body is remedied. Objective research studies have demonstrated that spasticity is reduced when ES is used on a daily basis and that spasticity can be expected to return when ES is discontinued.

Stabilization Of The Hip, Knee And Ankle For Standing, Shifting Weight And Moving From One Seat To Another

Incomplete SCI:

When the ability to stand on one foot in order to take a step or to walk is impaired by inadequate muscular support, ES can be used to give a sensory cue as a reminder to contract the muscles at the hip, knee and ankle or it can be used to help contract the muscles at the right time. It may not be possible to achieve a strong contraction of the deep hip muscles with skin electrodes, but it is quite practical to augment knee and ankle performance. It is usually necessary to use ES in exercise prior to seeing the optimal response in walking. Small, relatively inexpensive stimulators can be used for exercise and for standing and walking, when a footswitch trigger is available to turn the stimulation on at the same time the weight is transferred to the stance limb.

It has been demonstrated that electrodes or stimulation devices implanted directly on the deep muscles of the hip, and lower limb, are more effective than skin electrodes in controlling the hip and thigh muscles. The protocols employed were effective when a clinical therapy protocol was used in addition to a daily home ES program. At this time, however, there are no commercially available, implantable devices.

In both skin and implanted ES, it is extremely important that the ES is integrated into the physical therapy program designed to enhance volitional control and assure that new skills are learned as a result of the intervention. Because many incomplete SCI patients have sensation, electrical stimulation parameters must be chosen carefully to optimize comfort.

Complete SCI:

None of the electrical stimulation devices available today can mimic natural muscle recruitment and function. It is true, however, that ES can substitute for key muscle actions to permit standing and sitting without the use of a brace in some spinal cord patients. A simple, 2 channel stimulator with skin electrodes placed over the thigh and a trigger switch placed in the shoe or on a walker can allow the patient to stand up, reach for objects and sit down in a controlled manner. This is much preferred by many individuals to the process of wearing braces and locking and unlocking the knee joints of the braces.

Individuals with clinically complete SCI must be aware of the potential risks of using ES to generate functionally useful muscle contractions, or 40-60% of predicted force production in age-matched healthy individuals. Fracture of the lower extremity bones is a possibility because of the loss of bone mineral density in complete SCI. It is possible that ES will trigger autonomic dysreflexia, especially in the quadriplegic patient. Infection is not a problem with skin electrodes and it is a minimal risk with fully implanted ES systems. The use of an external stimulator and wire electrodes placed in the muscles presents an increased risk of infection. While infection has not been a major problem in most centers, the risk of infection is related to the electrode technology and the number of electrodes placed in an extremity.

Assistance In Bringing The Lower Limb Forward To Take A Step

Incomplete SCI:

When ES is applied over the leg muscles that are responsible for picking up the foot in the swing phase of gait, or when ES is applied to the peroneal nerve via an implanted ES device, the toes do not drag on the floor and there is less chance of tripping and falling. It also is possible that the ES may elicit a flexion reflex in the entire lower limb, allowing ankle, knee and hip flexion. This was first demonstrated in the early 1960's, and it is a commonly employed therapeutic approach in many physical therapy clinics, where the elicitation of this reflex is useful in reaching the goal of independent walking. It must be recognized that not all spinal cord injury patients will have this reflex to the extent that it can be useful for walking, but in those who do have it, it is possible to change from dragging the lower limb during walking to a brisk stepping response. The reliance on ambulatory aids, such as a walker or crutches, may be reduced or eliminated.

This therapeutic intervention may be accomplished with a variety of skin electrode devices, including those that are specifically engineered to accomplish limb advancement by the flexion reflex. These devices provide stimulation when the heel or foot is off the floor and

stimulation is turned off when weight is placed on the limb. This can be of particular interest for the patient who not only lacks the ability to pick up the foot for swing but also has difficulty shifting weight onto the limb after it is in contact with the floor. Weight must be shifted to the stance limb before the individual can take a step with the other leg. When stimulation does not turn off at floor contact, the patient is reminded to shift more weight and gait is improved. Implanted ES systems were first used for this purpose approximately 35 years ago, and implanted technology is available today in selected centers around the world.

Complete SCI:

The same principles discussed above under stance stability, apply to the application of ES for limb advancement and walking in complete SCI. While it may be important to SCI individuals to stand and take a few steps, functional walking is not possible with the ES systems of today. With all due respect to the technological advances that have been made in the last 40 years, ES cannot replicate the sophisticated neuromuscular control required for walking. Electrical stimulation cannot replicate the mechanical and metabolic refinements of normal locomotion, and patients who use ES systems pay a penalty in terms of inefficiency and increased energy demand. It is possible that future developments will permit refined control of muscle activity and adjustment of stimulation as needed during walking based upon feedback from joint positions or other mechanical and physiological measurements, but this will not happen in the immediate future. It must be recognized that any ES muscle contraction that is to substitute for volitional control in the completely paralyzed individual, must produce at least 40-60 percent of the predicted maximum force generation in an age matched, healthy individual, as well as demonstrate the necessary work production and fatigue resistance to be practical. It has been demonstrated that completely paralyzed muscles can be trained to this extent, but very few ES strengthening protocols have produced this functional level of muscle performance in the completely paralyzed muscle.

Considerations After Initial Recovery Has Plateaued

Continued Use Of Es To Maintain Joint Range Of Motion Or Correct Contractures

When the initial rehabilitation period has been completed and the return of volitional recovery has plateaued, the continued use of ES may be indicated to maintain joint range of motion or correct contractures. If the individual has volitional control of the extremity and spasticity does not cause abnormal posture or movement, ES should not be necessary. If joint stiffness or loss of range of motion do reoccur, ES may be indicated to gain range of motion and reduce spasticity.

Continued Use Of Es To Suppress Interfering Spasticity

Although some patients do not need continued ES for spasticity modulation, others may require it the rest of their life. This can be accomplished very economically with an inexpensive stimulator and an appropriate home program. It has been demonstrated that electrical stimulation need only be done for 1-2 hours per day to suppress unwanted muscle activity throughout the 24 hour period.

Continued Es To Encourage Muscles To Work Effectively For Daily Activities

When recovery of voluntary movement is incomplete, ES can continue to be used every

day. It is not uncommon to need some assistance with specific muscles or muscle groups such as the ankle or knee flexors, the hip abductors or stabilizers of the hip, or the elbow, wrist and finger extensors.

Neural Prosthetic Applications

When ES is used to support every day activities such as standing, walking or hand use, it may be called a "neural prosthetic" application. Neuroprostheses are devices which aim to substitute for the control of bodily functions which have been impaired by neurological damage. Some patients prefer to continue to use external ES systems or neuroprostheses. A small, inexpensive, wearable stimulator with skin electrodes may be the device of choice for simple applications requiring only a few channels of stimulation. The Handmaster external neuroprosthesis, developed in Israel, is a combined electrical stimulation and bracing system for control of the hand without the need for surgical intervention [NESS, Ltd]. The Parastep system offers 4 or 6 channels of skin electrode stimulation to allow standing and limited walking. The cost is increased for the additional channels and the Parastep protocol. The RGO II system [reciprocating gait orthosis with ES] is another application of combined bracing of the trunk and lower limbs with ES with the goal of improving walking over the use of the orthosis alone.

Other patients may choose to have an implanted ES system. Implanted ES systems have been successful in research studies and clinical trials in incomplete paralysis over the past 40 years. It has been demonstrated that either implanted electrodes or entire ES systems can facilitate control of specific muscles for joint stability and useful limb movement. The challenges are greater for the control of completely paralyzed muscles in walking [as previously discussed].

The Freehand system, developed at Case Western Reserve University in Cleveland, Ohio, is a fully implantable neuroprosthesis to give high quadriplegic candidates hand function. It has been very successful for those patients who passed the extensive test protocol to determine candidacy. This system has been available in recent years through trained health care teams in several countries [NeuroControl Corporation]. The cost of the system includes the stimulation hardware, surgical implantation and extensive therapeutic protocols to train the muscles and learn to use the system.

ES neural prostheses may require additional surgical intervention to assure optimal function. Tendon lengthening or transfer may be performed to improve volitional movement and to enhance the control afforded by ES.

Recent technological advances promise to bring new capabilities to the clinical world of ES in the years to come. Improvements in external and implanted ES technology will translate to improved clinical care. The injectable, microstimulator will offer the advantages of implanted ES control of one or many muscles, as required, without the need for surgery. In the future, it may be possible to control stimulation of the paralyzed limbs with signals generated in the brain in the same way that normal individuals control their movements.

Bladder And Bowel Management

The most common approach to restoring bladder function and achieving complete bladder emptying during urination has been the electrical stimulation of the ventral sacral spinal nerve roots by a fully implanted system. This system allows the clinically complete spinal cord injured patient to urinate on demand. The procedure may include surgical sectioning of the dorsal sacral roots to eliminate reflex incontinence. Thousands of patients have benefited from

this procedure, which was originated in the United Kingdom [The Finetech-Brindley Bladder Controller]. Candidates must be skeletally mature, neurologically stable and have intact reflex bladder contractions. The VOCARE system has been available in the USA and Belgium from NeuroControl Corporation during recent years.

Other research investigators are exploring the control of the bladder through ES of the peripheral nerves to the urinary bladder and to the sphincter muscles. ES systems to control emptying of the bowel may soon be available for spinal cord injured patients.

Bowel incontinence may be improved by ES of the nerves to the rectum and the anal sphincter muscle. When the peripheral nerve to the sphincter has been lost as part of the spinal cord injury, muscles from the hip or pelvic floor area that do have a nerve supply may be surgically transferred to make an anal sphincter muscle. This new sphincter muscle can be controlled by ES to provide bowel control.

Es For Fitness Or Cardiovascular Conditioning

ES is recommended in some centers for the severely or completely paralyzed paraplegic and quadriplegic. The goal is to provide a training effect that may result in health benefits and potentially fewer medical problems. Research findings demonstrate that electrically induced bicycling does cause an increase in oxygen uptake during the ES exercise, but the benefits of the lower extremity ES exercise have not translated into increased post-training cardiac output or oxygen uptake or any increased energy reserve for daily activities. The prescribed exercise protocols have been low in intensity and have not approximated what the paraplegic can do to train by propelling a wheelchair. For the paraplegic patient, it is important to compare any training outcomes with the potential training benefits of wheelchair training [which would not require the purchase of ES cycle equipment or clinical visits].

Of particular interest are the research findings of ES cycle exercise in patients with very high quadriplegia. Some high quadriplegic patients lose a significant amount of heart muscle in the months after SCI. It has been documented that this relatively low intensity exercise protocol may result in increased venous return to the heart with hypertrophy of the ventricular muscle and improved cardiac function. It has been proposed that such improvements in heart function may lead to greater longevity for the high quadriplegic.

Contributors:

J. M. Campbell, Ph.D., P.T., 2002

Acknowledgements:

R. Acimovic-Janezic, Prim. Dr.,
T. Bajd, Dipl. Ing. Dr.,
N. Donaldson, Ph.D.,
R. Nathan, B.M.E.,
D.N. Rushton, M.D.,
U. Stanic, Dr.,

See:

- General Considerations in the Clinical Applications of Electrical Stimulation
- Muscle Weakness or Paralysis with Compromise of the Peripheral Nerve
- Management of Bladder and Bowel Incontinence

- References:
 - ES in Spinal Cord Injury
 - ES for the Prevention of Deep Venous Thrombosis
 - Comfort in Electrical Stimulation
 - ES for Improving Joint Range of Motion
 - ES in the Modulation of Spasticity
 - ES in Wound Healing
 - ES in the Management of Bladder and Bowel Incontinence
 - ES in Muscle Denervation
 - ES in Muscle Reinnervation