0749-0712/97 $0.00 + .20

ELECTRICAL STIMULATION AND THE TREATMENT OF COMPLEX REGIONAL PAIN SYNDROMES OF THE UPPER EXTREMITY

William P. Cooney, MD

Clinical, intractable pain in the upper extremity often results from neuroma, direct injury to a peripheral nerve, or repetitive operative insults to a peripheral nerve that has compressive neuropathy.[1, 4, 11, 12, 13] The patient presents to the physician with chronic peripheral nerve pain, and, often, an extremely difficult physician–patient management problem ensues. In our experience,[3, 14] such patients have had two or more operative interventions on a peripheral nerve. The surgical treatment is unsuccessful and chronic pain dysfunction results. The most common involvement is the ulna nerve through the cubital tunnel and, secondly, the median nerve at the wrist. The patient's level of pain is often severe, incapacitating him or her with respect to performing activities of daily living and significantly interrupting sleep. The majority of such patients have required narcotic pain medications, either intermittently or continually. They have been through a number of pain management programs, and a variety of neuroleptic agents have been prescribed in an attempt to reduce the level of perception of peripheral nerve pain.

When patients with chronic pain are referred by pain management centers or surgeons who treat injuries to the upper extremity, we are often presented with a patient who is depressed, angry, and, not uncommonly, hostile toward the medical profession. They are stressed both physically and mentally as a consequence of nearly intractable pain for which all modalities of pain management have been attempted and failed.

Based on our experience with this type of patient, we present expectations with operative intervention for chronic limb pain using a system of direct electrical stimulation of the involved peripheral nerve. We have found that electrical stimulation applied directly to a single peripheral nerve can provide sufficient relief of pain that improves patient outlook, both mentally and physically; increases or improves lasting sleep, releases the individual from addictive narcotic pain medication; and, importantly, restores a psychological sense of well being.

BASIC SCIENCE BACKGROUND

For this issue on pain dysfunctional syndromes, we present concepts of management using direct electrical stimulation. The theory upon which direct electrical stimulation of peripheral nerves is based originates with the

From the Division of Hand Surgery, Department of Orthopedics, Mayo Clinic, Rochester, Minnesota

work of Melzack and Wall.[8, 17] They suggest that peripheral limb pain is controlled by a gate mechanism in which transmission cells are influenced by outside stimuli. By blocking the firing of the transmission cells, the experience of pain can be controlled. They noted that large α peripheral nerve fibers inhibit the transmission of small β fibers that stimulate a cellular response of pain. The gate theory proposes that electrical stimulation of large α fibers, in effect, reduces pain perception by (1) inhibiting the activity of the smaller β fibers, (2) producing various blocks to nerve interfaces with stimulating sensations in the autonomous nerve zones, or (3) directly stimulating dorsal column cells in the spinal cord.[4] Effective electrical stimulation is "the closing of the gate to chronic pain."[17]

CLINICAL EXPERIENCE

Patients who present to us typically have pain in the extremity that appears to be the result of overwhelming, uninhibited sensory stimuli that embrace the central nervous system such that even minor perceptions of cold, touch, vibration, or moving impulses stimulate a painful awareness. The pain that presents is somatically derived pain and is completely separate from sympathetic overstimulation—reflex sympathetic dystrophy.[4] Screening tests, such as the bone scan and quantitative sensory testing, are unremarkable.[5] Often, there are local trigger areas that can be effectively quieted by local injections of anesthetic agents.

To date, we have identified 60 patients who have met the criteria of a painful peripheral nerve and who would benefit from direct electrical nerve stimulation. The patient usually has involvement of the upper extremity (radial, ulna, and median nerves), although the lower extremity (peroneal and sciatic nerves) has been involved in six of our patients.

The majority of patients reported continued use of narcotics for pain relief, including the use of codeine, meperidine, Percodan (DuPont de Nemours, Wilmington, DE), and hydromorphone. Sleep disturbance was a significant factor in their presentation, as was depression. Often, the patient demonstrated increased hostility to friends and family. Psychiatric evaluation and a Minnesota Multiphasic Personality Inventory suggested pain dysfunction and depression. Trials of percutaneous electrical stimulation were often helpful but not permanent. Pain management by a series of peripheral nerve blocks or supraclavicular plexus blocks were either not effective or only temporarily effective. Trials of peripheral nerve blocks that reduced pain in the specific autonomous zone were quite helpful in determining which patients would benefit from direct electrical stimulation.[7, 14]

TECHNIQUE OF ELECTRICAL STIMULATION

Each patient who underwent electrical stimulation had a complete surgical exposure of the affected peripheral nerve. As required

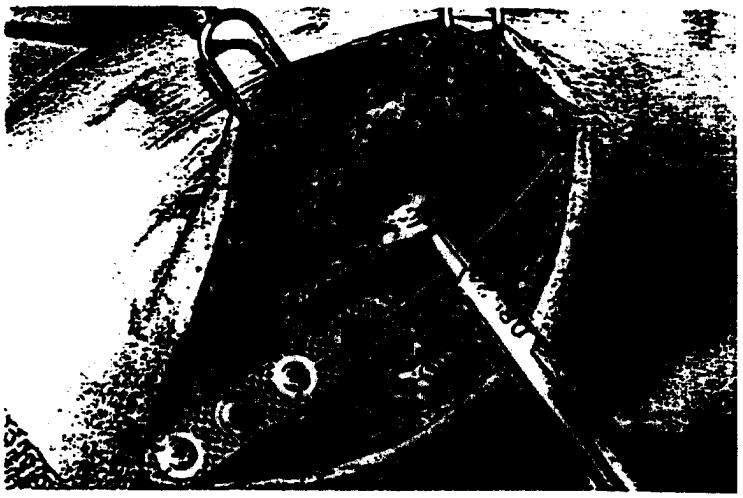

Figure 1. The electrode placed beneath the ulnar nerve. A wall of connective tissue (fascia, fat, or muscle) separates the electrode from direct contact with the nerve.

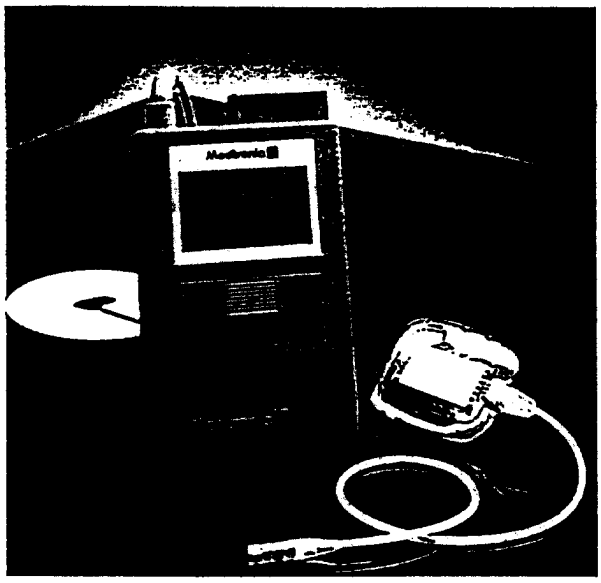

Figure 2. The SE-4 (Extrel) electrical stimulation system components include upper left the receiver coil which is attach to the stimulation unit *(center)*. The receiver unit *(right)* is placed in the subcutaneous tissue of the flank or chest wall. The receiver coil is placed over the receiver unit and transmits the electrical signal from the stimulation unit.

for that exposure, neurolysis of the involved nerve was performed. After freeing the peripheral nerve and performing appropriate ancillary procedures to provide a scar-free bed, the first stage of the direct electrical stimulation was initiated. That stage consisted of placing the stimulating electrode adjacent to the involved peripheral nerve and connecting it to an exteriorized connecting lead. An interval of fascia or muscle was generally placed between the simulating electrode pad and the involved peripheral nerve to serve as a soft-tissue barrier to prevent direct contact between the nerve and the electrode (Fig. 1). A percutaneous connecting lead brought out proximally allowed for external stimulation of the involved nerve.

A trial of electrical stimulation was then performed by connecting the outside lead to a screening unit (Fig. 2). The latter allowed for changes in amplitude, rate, and pulse width of the electrical stimulating unit. The electrode lead (resume lead) contained four electrode or contact points (Fig. 3). The screening session allowed one to choose different electrode combinations and polarities and to determine which sequence or combination produced the optimum level of pain relief. The screening period lasted from 5 to 8 days, with a maximum of 14 days in two patients. The patient was asked to complete a pain record and to note any changes in extremity function.

If a patient had successful reduction of pain and elimination of the use of narcotic pain medication, a stage 2 procedure was initiated (Fig. 4). In the second stage, the electrode was attached to either an internal or external power source that was designated as the "pulse generator." In both systems, a power source is inserted in the flank to provide an impulse for electrical stimulation. Two different power sources have been used. The first and initial experience was with the Medtronic SE4 transmitter, now referred to as the Extrel electrical stimulating unit. The unit has an

Figure 3. The four-pad electrode is shown adjacent to the ulnar nerve (identified by the forceps to the right).

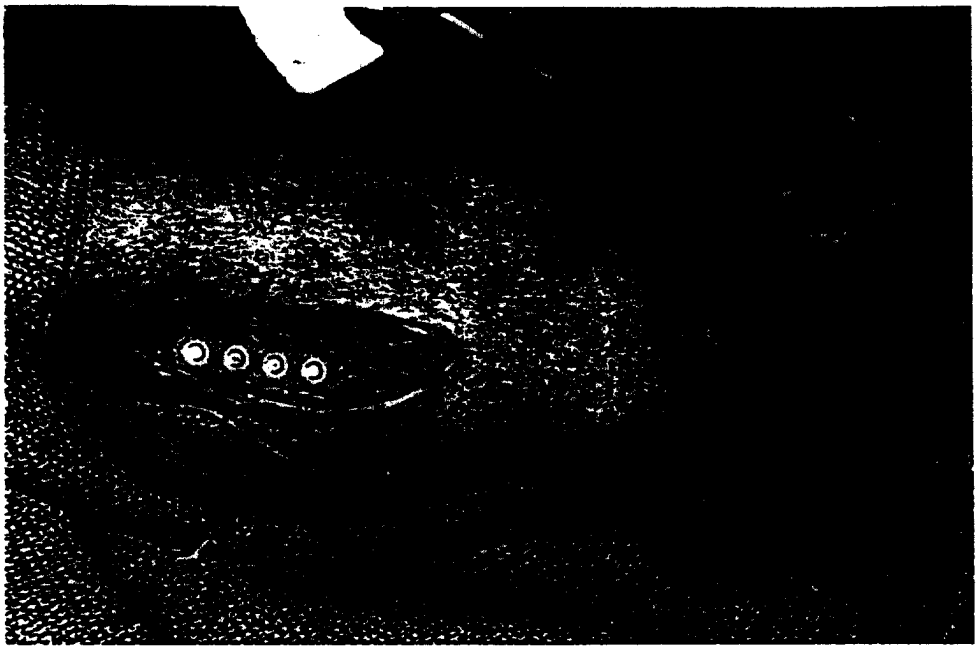

Figure 4. The right arm is shown with the electrode place adjacent to the ulnar nerve. The connecting lead is passed subcutaneously toward the shoulder where it exits for attachment to a connecting lead from the pulse generator.

external power source that transmits a signal to an internal receiver. The second unit is an implantable Itrel Unit, in which the pulse generator remains permanently implanted in a subcutaneous pocket in the flank (Fig. 5). The Itrel unit has its own built-in power source, much like a cardiac pacemaker. The unit can be activated and controlled quite effectively by means of telemetry. The latter has advanced programming capabilities, allowing external adjustment by a trained technician or nurse using a portable, console programmer (Fig. 6). The rate, amplitude, and pulse width, including the stimulating mode (continuous or cyclic stimulation with a soft start), can be selected for each patient and a printout of the parameters as well as a record of actual application of the electrical stimulation system can be evaluated at each patient visit.

It is important that, in the immediate postoperative period, rehabilitation of the limb be performed, including a full range of shoulder and elbow motion. The connecting leads, which are covered with polyethylene, do produce a foreign body reaction with variable

Figure 5. Pulse generator held in the hand. This Itrel unit is like a cardiac pacemaker in that it can be programmed to send out a specific pulse signal of a known rate and amplitude. It has a battery life approaching 4 years.

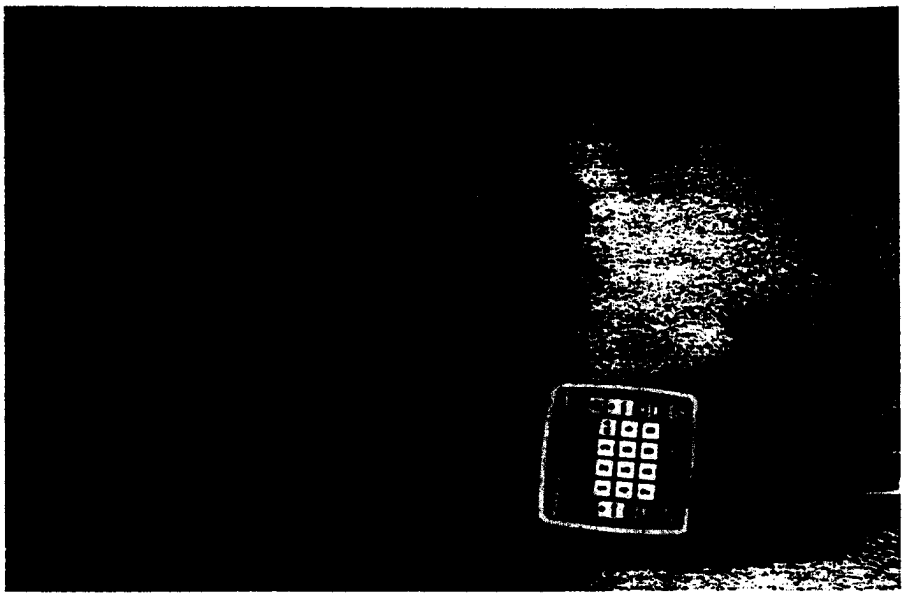

Figure 6. External programming is demonstrated by a hand-held unit that transmits a signal to the pulse generator. This unit can turn on or off the pulse sequence and allow the patient to control the rate and amplitude of the electrical signal.

degrees of fibrosis that can limit motion and place tension on the connecting lead. Patient follow-up is also very important because variability in the amount of electrical stimulation can occur with time and adjustments in the amplitude and pulse rate and width may be needed.

Each patient who underwent electrical stimulation has had a careful follow-up of the degree of pain relief, need for narcotic pain medication and an assessment of abilities to use the affected limb. A pain score was derived and an activity-of-daily-living assessment was performed. If the first stage of electrical stimulation is successful, then second-stage implantation of the pulse generator and its connecting leads is performed. If the screening period is not successful in reducing pain, then the electrode system is removed and other forms of pain management are considered.

FOLLOW-UP ASSESSMENT

Patients are evaluated at weekly intervals in the immediate postoperative period and then at quarterly intervals for up to 3 years. In assessing the results of our patients, we find there is variation in the degrees of success and failure related to use of the electrical stimulating unit. In general, approximately one third of our patients are improved substantially, such that they are able to return to work without restriction, do not take narcotic pain medication, and sleep soundly during the night. The second third of our patients have improved pain, but not complete relief of pain. Those patients may return to work, but not to the original type of employment. They may still require pain medication during the day and narcoleptic agents at night. In general, they have not required narcotic pain medication. The final third group of patients have had little or poor success with direct electrical stimulation and, in the majority, the unit has been removed.

Pain was evaluated postoperatively using the Mayo Pain Scale, the presence or absence of narcotic pain medication, and a test of functional abilities and activities of daily living.[3, 14] It is quite well recognized that evaluation of pain is subjective and that many patients have other significant psychological factors that influence their perception of pain. We found it very difficult preoperatively to determine which patients would benefit from the pain management programs. In general, the results of treatment of chronic ulna nerve pain have been good to excellent, with 80% of patients having noticeable relief of their previous level of pain and discomfort. We had patients with ulna nerve pain secondary to direct injury, for example, who were completely incapacitated from peripheral nerve pain, who had failed cubital tunnel releases on at least two or three previous occasions, and who were nearly nonfunctional as a re-

sult of chronic nerve pain. At our institution, ulna neurolysis combined with revision of the anterior transposition to the deep submuscular position and electrical stimulation have often resulted in good pain relief and cessation of narcotic pain medication. Such patients have been able to return to work and have improved self esteem; resolution of previous, often incapacitating, depression; and, in general, improved family lives. Although not all of these patients were pain free, they were improved to a point at which they could cope and function on a more normal level on a daily basis.

On the other hand, a number of the patients with chronic median nerve pain, usually at the carpal tunnel, following previous attempts at carpal tunnel release and neurolysis, were not substantially improved with electrical stimulation. Reasons for the difference were not clear. The site of stimulation (above the elbow) was farther away for the median nerve than the ulnar nerve. Median nerve patients had a greater number of internal neurolysis procedures than those with ulnar nerve involvement. At the wrist, there may be less soft-tissue bed and revascularization potential than at the elbow, where most patients had deep submuscular transposition of the ulnar nerve. Local muscle and fascia

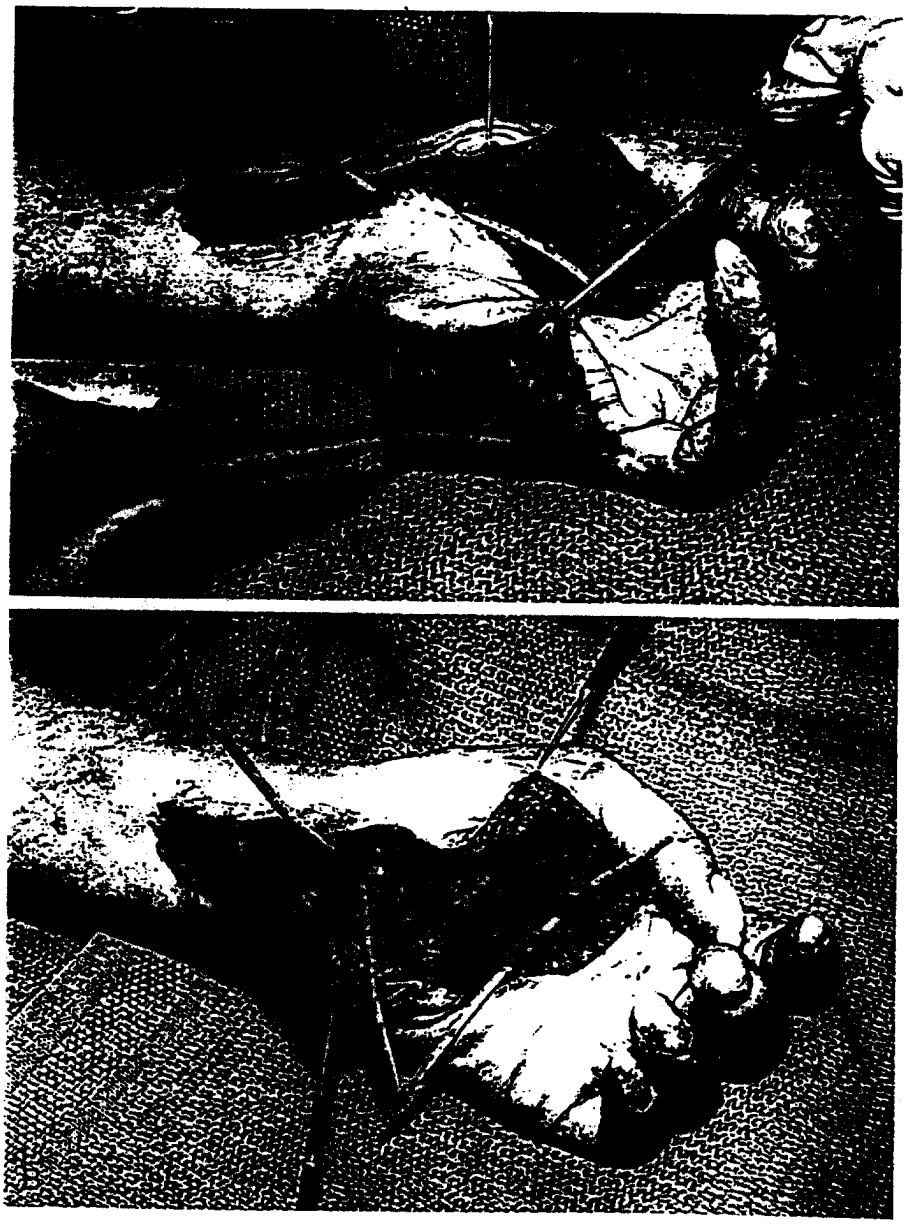

Figure 7. For chronic median neuropathy, a hypothenar fat pad is dissected out *(A)* and transferred over the median nerve *(B)*. Proximally at the elbow, electrical stimulation of the median nerve was performed to assist in postoperative pain control.

flaps have been rotated around the median nerve and combined with electrical stimulation above the elbow (Fig. 7).

Complications related to the electrical stimulation system have been few. They include three patients with lead failures and one patient with an unconfirmed receiver malfunction. There have been five patients in whom the electrode has rotated from its normal position against the nerve, requiring replacement of the electrode.

At this time, we continue selected use of direct electrical stimulation of peripheral nerves. The US Food and Drug Administration is in the process of reviewing the role of direct electrical stimulation of peripheral nerves in comparison with spinal cord stimulation for low back pain radiculopathy. The requirements for electrical stimulation of peripheral nerves currently preclude the use of the Itrel Unit until a comparative prospective study has been initiated. The majority of our patients now have the Extrel external programming unit combined with an internal receiver and electrical stimulating conduction system. We continue to see patients who are effectively improved by the use of direct electrical nerve stimulation—particularly those who have been carefully selected for this program.

DISCUSSION

The application of direct electrical stimulation of peripheral nerves is not a new concept.[2, 6, 7, 9, 10, 12, 13, 15, 16] The original programs consisted in wrapping an electrode around the peripheral nerve, providing a single source of direct current stimulation. A fibrous response around the nerve often resulted, limiting the effect of the stimulation to a few months. Control of the degree and duration of stimulation was not present. Results from the early series suggest an average of 60% patient improvement, but long-term follow-up assessment was lacking. The experience from the Duke Medical Center was quite encouraging, for example, but late problems of recurrent pain after both direct peripheral nerve stimulation[11] and dorsal column stimulation[10] led other investigators to question the techniques and anticipated results.

Our experience has been somewhat different, although there are clearly patients who do not benefit from such a program of nerve stimulation.[3] Patient selection is critical; we insist that each patient has a complete physical examination, psychiatric assessment, and review in our pain clinic.[14] The patient must have complete relief of pain following peripheral nerve block of the involved nerve to be considered for this program. Psychiatric assessment is also important. Most of our patients have had chronic pain for several years and the impact on their lives is substantial. With appropriate counseling and an improved level of pain relief, a clear majority of patients adapt to their pain level and return to productive lives. Pain management through use of electrical stimulation provides them an element of hope and understanding. To date, of the 60 patients we have followed over 2 years, the success of pain relief is over 80%, with about 60% having nearly complete pain relief and 20% having a level of tolerable pain relief. We continue to recommend direct electrical stimulation of painful peripheral nerves in patients in whom we can document somatic perineral nerve pain.

References

1. Blumberg H, Janig W: Discharge patterns of afferent fibers from a neuroma. Pain 20:335–353, 1984
2. Campbell JN, Long DM: Peripheral nerve stimulation in the treatment of intractable pain. J Neurosurg 45:692–699, 1976
3. Cooney WP III: Chronic pain treatment with direct electrical nerve stimulation, chapter 105. *In* Gelberman RH (ed): Operative Nerve Repair and Reconstruction, vol II. Philadelphia, JB Lippincott, 1991, pp 1551–1561
4. Lankford LL: Reflex sympathetic dystrophy. *In* Hunter JM (ed): Rehabilitation of the Hand, ed 2. St Louis, MO, CV Mosby, 1984, pp 509–532
5. Law PA, Caskey PE, Tuck RR, et al: Quantitative sudomotor axon reflex test in normal and neuropathic subjects. Ann Neurol 14:573–580, 1983
6. Law JD, Swett J, Kirsch W: Retrospective analysis of 22 patients with chronic pain treated by peripheral nerve stimulation. J Neurosurg 52:482–485, 1980
7. Long DM: Electrical stimulation for relief of pain from chronic nerve injury. J Neurosurg 39:718–722, 1973
8. Melzack R, Wall PD: Pain mechanism: A new theory. Science 150:971–979, 1965
9. Meyer GH, Fields HL: Causalgia treated by selective large fiber stimulation of peripheral nerve. Brain 95:163–168, 1972
10. Nashold BS, Friedman H: Dorsal column stimulation for control of pain: Preliminary report on 30 patients. J Neurosurg 36:590–597, 1972
11. Nashold BS, Goldner JL, Mullen JB, et al: Long-term pain control by direct peripheral nerve stimulation. J Bone Joint Surg Am 64:1–10, 1982
12. Picaza JA, Cannon BW, Hunter SE, et al: Pain suppression by peripheral nerve stimulation. Part II: Observations with implanted devices. Surg Neurol 4:115–124, 1975

13. Racz GB, Browne T, Lewis R: Peripheral stimulator implant for treatment of causalgia caused by electrical burns. Tex Med 84:45–50, 1988
14. Strege DW, Cooney WP, Wood MB, et al: Chronic peripheral nerve pain treated with direct electrical stimulation. J Hand Surg Am 19:931–939, 1994
15. Sweet WH, Wepsic JG: Treatment of chronic pain by stimulation of fibers of primary afferent neurons. Trans Am Neurol Assoc 93:103, 1968
16. Waisbrod H, Panhaus CH, Hansen D, et al: Direct nerve stimulation for painful peripheral neuropathies. J Bone Joint Surg Br 67:470–472, 1985
17. Wall PD, Sweet WH: Temporary abolition of pain in man. Science 155:108–109, 1967

Address reprint requests to
William P. Cooney, MD
Department of Orthopedics
Mayo Clinic
200 First Street, SW
Rochester, MN 55905