42 Peripheral Nerve Stimulation: Current Concepts

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This chapter focuses on aspects of using electrical stimulation delivered via electrodes surgically implanted adjacent to peripheral nerves to treat painful conditions. The state of the art from a clinical perspective (e.g., equipment, patient selection criteria, stimulation parameters) is presented, followed by a brief discussion of the evolution of the technique as well as mechanism(s) whereby the therapy is thought to act.

STATE-OF-THE-ART TECHNIQUE AND EQUIPMENT

The technique of peripheral nerve stimulation (PNS) is relatively simple, with exposure of the nerve and placement of an electrode along the side of the nerve or underneath it. The nerves commonly used for PNS are the median, ulnar, radial, common peroneal, and posterior tibial nerves.

The implantation is done by a qualified surgeon. Usually, a two-step surgical procedure is used, ending with both the peripheral nerve stimulator (programmable receiver, battery pack) and the electrodes totally implanted. The system is programmed by a portable transmitter that is placed over the subcutaneously buried programmable receiver and battery pack during programming. The first step of the procedure is implantation of the stimulating electrode, followed by a trial period (usually about 3 days). An external battery pack is used during the trial period. If adequate pain relief is obtained during the trial period, the second step of the surgery, implantation of the battery pack, is completed.

A paddle-type electrode (e.g., Resumé, manufactured by Medtronic, Inc.) utilized in spinal cord stimulation is also used for peripheral nerve stimulation. The electrode is usually placed proximal to the injury site. During implantation of the electrode, a thin layer of fascia is placed between the nerve and electrode. The rationale for this maneuver is that fascia reduces irritation of the nerve by the electrode and discourages proliferation of fibrous tissue around the electrode. The resulting situation is considered to be analogous to use of epidurally placed electrodes for spinal cord stimulation, wherein the electrode and the cord are separated by the meninges.

The electrodes usually have at least four contacts. Such a design allows selection of the optimal positive and negative electrode configuration using bipolar stimulation. The goal is to position the electrodes in a configuration such that when stimulation is applied, the patient perceives sensation in the painful area.

The programmable stimulating battery pack (e.g., Itrel, manufactured by Medtronic, Inc.) allows one to select the electrodes to be stimulated, pulse duration (μsec) and intensity (volts), pulses per second, and stimulation on-and-off cycling. The usual initial settings are 190 to 400 μsec, 0.75 to 1.25 volts, 65 to 85 pulses per second, and 64 seconds on, 2 minutes off. The appropriate voltage is found by increasing the stimulus intensity by 0.25-volt increments until the patient reports perception of stimulation. Optimal settings are then set by increasing or decreasing pulse duration. The reader may find further details regarding the implantation technique in the *Peripheral Nerve Stimulation Surgical Technique Notebook* available from Medtronic, Inc. (Minneapolis, MN).

PATIENT SELECTION

Pain in the distribution of a single traumatized peripheral nerve constitutes the best indication for peripheral nerve stimulation (PNS).[1] Good results with two nerve implants have been reported, however.[2] Good results have also been obtained when stimulation was applied to a nerve that, after injury, produced localized pain that subsequently spread to other areas of the body.[1] Patient selection criteria are listed Table 42–1.

Pain reduction with a trial of transcutaneous electrical nerve stimulation (TENS) or with local anesthetic nerve block has been advocated as a screening procedure for PNS. Results from at least one study indicate that pain that is lessened by TENS is somewhat more likely to respond favorably to PNS.[3] A negative response to TENS, however, should not in itself exclude a patient as a candidate for PNS. There are data indicating that pain relief with nerve blockade does not ensure a favorable response to PNS, but continued pain despite a technically adequate nerve block makes it very unlikely that electrical stimulation of the same nerve will be successful.[4]

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TABLE 42–1. Patient Selection Criteria for Peripheral Nerve Stimulation

General criteria	Pathology for the pain complaint demonstrated
	Cause of pain isolated to a single nerve (see text)
	No nerve abnormalities demonstrable
	More conservative therapies failed
	No serious drug habituation problems detected
	Psychological clearance obtained
	Trial stimulation successful
	Correctable pathology (e.g., nerve entrapment) excluded
Conditions causing intractable pain for which PNS may be indicated	Direct or indirect nerve trauma
	Reflex sympathetic dystrophy
	Causalgia
	Postherpetic neuritis
	Sciatica
Conditions generally not responsive to PNS	Pain associated with failed low back surgery
	Cancer pain
	Idiopathic pain
	Pain due to nerve root injury

COMPLICATIONS AND OUTCOMES

Complications of PNS are as follows:

- Infection
- Battery failure
- Broken wires
- Fluid shorting electrical connections
- Changing contact between electrodes and nerve
- Scarring between nerve and electrode
- No response to trial stimulation, leading to electrode removal
- Interference with cardiac pacemakers
- Tissue damage when PNS equipment transmits output of radiofrequency (RF) devices (e.g., electrocautery, RF lesioning) to electrode contacts

Patients with implanted PNS systems should be given a medical card recommending exemption from x-ray security checks to avoid alterations of the PNS program by the x-ray equipment. They also should avoid areas where microwave ovens are in use. Reports indicate that success rates in excess of 80% (mild to marked relief of pain) can be achieved with PNS.[5–7] In our experience, adjunct therapy may be needed. For instance, sympathetic nerve blocks may be required to deal with "sympathetic storms" during the first year after implant. The general tendency over time is for patients who gain long-term benefit from PNS to progressively improve and then become less reliant on PNS. PNS usually is a long-term commitment, however, requiring good communication among the referring physician, the patient, and personnel at the center where the implantation is done.

EVOLUTION OF PNS

Electricity was used empirically in medicine as early as the Socratic era (Table 42–2). The scientific basis for the use of PNS as pain therapy was provided by Melzack and Wall's[8] spinal gate control theory in 1965. Wall and Sweet[9] conducted the first chemical test of the spinal gate control theory on eight patients with chronic cutaneous pain in 1967.

A number of groups reported their experience with PNS in the late 1970s and early 1980s. Little information was published on the procedure over the next 10 years. The initial patient experiences helped define patient selection criteria and improvements needed in the technique and the equipment. Initially, circumferential cuff electrodes were used. In isolated instances, small electrodes inserted directly into the nerve were used. Later, equipment originally designed for spinal cord stimulation was adapted for PNS.

MECHANISM(S) OF ACTION

WHAT IS STIMULATED?

The intensity of stimulation is adjusted so that the patient perceives a tingling sensation in the affected area. This is the first sensation elicited by the stimulation and hence is due to excitation of low-threshold sensory (afferent) nerve axons (e.g., A-beta). In carefully controlled laboratory conditions, a reproducible strength (voltage)–duration (μsec) curve can be produced for different classes of nerve fibers (with different thresholds). A voltage below which axons cannot be activated, no matter how long the pulse duration, can be defined. Similarly, a pulse duration below which axons cannot be activated, no matter how great the voltage, can be determined. Between these extremes, combinations of pulse duration (width) and voltage that excite one or more populations of nerve fibers can be determined. This is the general basis for the selection of the initial voltage used for PNS and fine tuning of the stimulus by adjustment of pulse duration.

Current flow, not voltage, produces excitation and may vary if resistance to current flow changes, but voltage is held constant as is done with PNS stimulators. Resistance to current flow from the PNS electrodes to the nerve varies if, for example, the distance between the electrode and the nerve changes (decreases if closer, and hence more current flow; increases if farther apart, and hence less current flow). Obviously, decreasing current flow reduces intensity of stimulation (no sensation may be aroused), and increasing current flow increases stimulation intensity (the patient may have motor movements or experience sensations other than tingling, e.g., pain).

Stimulation frequency can also influence the stimulus volt-

TABLE 42–2. Evolution of Peripheral Nerve Stimulation (PNS)

Socratic era	Electrogenic torpedo fish to treat pain of arthritis and headache (Scibonius Longus)
Middle Ages	Electrostatic generators combined with Leyden jars
19th century	Discovery of electric battery led to continued investigation of electroanalgesia
Modern era (beginning in 1965)	Melzack and Wall's spinal gate control theory provided scientific basis for use of PNS
	First clinical test by Wall and Sweet in 1967

age and duration required to activate a nerve fiber population; lower values are needed as stimulation frequency increases. This is one reason why a low-frequency stimulation may produce a tingling sensation and a high-frequency stimulation with the same voltage and pulse duration produces pain.

HOW DOES STIMULATION OF LOW-THRESHOLD AFFERENT AXONS PRODUCE ANALGESIA?

The most widely accepted explanation of how low-threshold afferent activation produces pain relief is via activation of local inhibitory circuits within the dorsal horn of the spinal cord. These inhibitory circuits then act to diminish nociceptive transmission through the spinal cord. Another proposed mechanism is that PNS produces a nondecipherable code, thereby "jamming" sensory input to the central nervous system. What must be kept in mind is that electrical stimulation of a peripheral nerve delivers a synchronous volley of activity to the spinal cord from a large number of axons, something that usually does not happen in everyday life.

SUMMARY

Peripheral nerve stimulation has found a niche in contemporary pain management. Current concepts have been discussed herein. Our understanding of how PNS acts to relieve pain, however, as well as improvements in the technique and equipment, is rapidly evolving.

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