Stimulation of the Peripheral Nervous System for the Painful Extremity

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Abstract
Peripheral nerve stimulation and, recently, peripheral nerve field stimulation are excellent options for the control of extremity pain in instances where conventional methods have failed and surgical treatment is ruled inappropriate. New techniques, ultrasound guidance, smaller generators, and task-specific neuromodulatory hardware and leads result in increasingly safe, stable and efficacious treatment of pain in the extremities. Peripheral nerve stimulation has shown to be an increasingly viable option for many painful conditions with neuropathic and possibly nociceptive origins. This chapter focuses on the historical use of neuromodulation in the extremities, technical tasks associated with implant, selection of candidates, and potential pitfalls of and solutions for implanting devices around the peripheral nervous system for extremity pain.

Stimulation of the peripheral nervous system for the treatment of pain has enjoyed renewed interest over the past several years as the modalities of delivery have become more robust and techniques have emerged that not only provide increased safety and ease of delivery but also improved success for the patient. While peripheral nerve stimulation (PNS) has been more common in the periphery, new techniques surrounding peripheral nerve field stimulation (PNFS) have recently emerged. Good outcomes have been demonstrated in the treatment of many painful conditions such as inguinal neuralgia, chronic regional pain syndrome, intercostal neuralgia, carpal tunnel syndrome, the painful postsurgical knee, traumatic and entrapment injury and focal pain of neuropathic and possibly nociceptive origins. The relatively early works of Weiner, Hassenbusch and Stanton-Hicks and others demonstrated that neuromodulation of the peripheral nerve resulted in paresthesia of the sensory distribution of the distal neural territory. However placement required great technical skill in the dissection to the target, and then in the placement of the neural electrodes in manner...
that provided good sensory stimulation, often in a mixed nerve, as well as consider-
erations of fascial and flap grafting to guard against neural injury. Additionally, the
procedures were time consuming and poorly reimbursed. New, percutaneous place-
ment of electrodes, however, has led to an improved level of access for patients, and
provided a safe, easy and relatively swift procedural option for the long-term treat-
ment of extremity pain.

This chapter will focus on the historical use of neuromodulation in the extremities,
technical tasks associated with implant, selection of candidates, and potential pitfalls
and solutions of implanting devices in the peripheral nervous system for extremity
pain.

Review of the Literature

Some 40 years ago, Wall and Sweet [1] inserted an electrode into the infra-orbital
foramen and found diminution in neuropathic pain. They then successfully treated
neuralgias using partially implanted percutaneous PNS [2– 4]. Later, Sweet and
Wepsc stimulated the median and ulnar nerves for the treatment of causalgia [5].
Variable success was reported in subsequent case series, 58% [6] and 52.6% for upper
extremity pain relief and 31% relief for lower extremity pain [7, 8]. Difficulty with
foreign body reaction related to the direct contact of the electrode on the exposed
nerve limited the therapy until surgical technique utilizing fascial flap from nearby
intermuscular septa was used to create a barrier between the nerve and the exposed
electrode [9]. Stanton-Hicks suggested the following four criteria for patient selec-
tion: neuropathic pain in the nerve distribution, demonstration of pain relief by up to
3 targeted nerve blocks, exclusion of confounding psychosis, and positive response to
transcutaneous electrical nerve stimulation (TENS) [10]. Over the ensuing decades
of the 1970s, 1980s and early 1990s, many small series were published utilizing a vari-
ety of electrodes and techniques for direct nerve stimulation, or implantation in the
vicinity of the peripheral nerve proximal to the region of pain to generate paresthe-
sia distal to the implanted electrodes. Reports of long-term success were elusive, and
results complicated by erosion, injury from the electrode insertion, and fibrosis in the
peri-electrode area made the appeal of PNS largely wane in comparison to the success
and ease of dorsal column stimulation [11]. However, by the late 1990s with improv-
ing technique, Long [12] produced a quite favorable meta-analysis showing positive
effect in the reduction of pain in 82.5% of patients including sufferers of neuroma
pain, painful diabetic neuropathy and post traumatic neuropathy [4, 13, 14]. Weiner,
Reed, Slavin and Burchiel were credited with renewing interest in PNS as they intro-
duced percutaneous approaches to electrode implantation for remediation of greater
occipital neuralgia and craniofacial pain syndromes [15– 17]. Additionally, in the late
1990s, following Racz’s publication refocusing PNS on CRPS [9], Hassenbusch et al.
[18] published a prospective series of consecutive patients with chronic regional pain
syndrome in the distribution of a single major peripheral nerve. He and his team implanted paddle electrodes on the affected nerves and tested them for 2–4 days, followed by generator implant if 50% or more pain reduction was achieved during the trial. Two thirds of the patients, followed for 2–4 years, reported good or fair relief and pain was reduced from 8.3 to 3.5 on the numeric pain rating scale at follow-up. Eisenberg et al. [19] published a large retrospective analysis looking at long-term follow-up (3–16 years) of patients with PNS for nerve lesion reporting ‘good’ results in 78% of patients and an average drop in VAS from 6.9 preoperatively to 2.4 postoperatively. Mobbs et al. [20] retrospectively studied 45 patients with pain as result of nerve trauma. At a mean follow-up of 31 months the pain relief judged as good (>50% improvement) by about 60% of patients, and fair or poor in the remaining 40%. About half of patients reported increased activity levels. Long-term clinical outcomes of peripheral nerve stimulation for peripheral neuropathic pain were investigated by Van Calenbergh et al. [21] showing good clinical outcomes in 5 patients who underwent implantation of the Avery circumferential electrode in the upper extremity.

Historically, most implanters have described dissection to a named nerve and direct application of either a ring or paddle lead in the vicinity of the nerve; this technique is technically demanding, has significant complication rate and requires a considerable amount of operative time, and so recently interest in percutaneous trialing and permanent implantation has arisen. Speaking to that need, Monti [22] described percutaneous placement of electrodes for stimulation of the brachial plexus in the interscalene space. The rise of ultrasound-guided injections and interventions has recently turned attention to the use of ultrasound to negate the need for direct dissection for peripheral nerve visualization as ultrasound can effectively characterize the peripheral nerve by density. Narouze et al. [23] have described ultrasound-guided placement of percutaneous electrodes next to the femoral nerve, and Huntoon and colleagues [24–26] in a series of papers, have quite elegantly described a host of approaches for ultrasound-guided deployment of percutaneous PNS electrodes for neuropathic pain of the extremities.

While the organization of the peripheral nervous system allows direct named nerve stimulation for extremity pain, peripheral nerve field stimulation shows early promise for localized extremity pain. While described by many authors for stimulation of focal and radiating pain in the head, neck and trunk, McRoberts and Roche [27] illustrated successful PNfS in the knee for localized chronic knee pain following knee arthroplasty. Other localized pain in the extremity, and especially that which crosses the sensory fields of multiple nerves may also be amenable to PNfS.

**Mechanism of Action**

While long observed that pain responded to touch, Melzack and Wall’s 1965 introduction of the gate control theory of pain changed the paradigm of pain epistemology,
and opened the door for new ideas about the modulation of pain [28]. Their theory supported the concept of activation of A-beta fibers which conduct the innocuous stimuli of vibration and position, and activate inhibitory interneurons within the substantia gelatinosa in the apex of the posterior horn and subsequently influence the wide dynamic range neuron onto which both the large and small pain fibers synapse. When activated, it is theorized, the gate closes and inhibits the cephalad conduction of pain. Although some recent evidence has questioned interneuronal inhibition, the concept of early large fiber recruitment inhibiting small fiber conduction remains the basis of the theory of electrical stimulation and subsequent pain inhibition. Electrical stimulation of A-beta fiber afferents within peripheral nervous system is postulated to inhibit transmission of A-delta and C fibers, but applicability of this concept to stimulation remains somewhat controversial. However, recently Ellrich and Lamp [29] showed the ability of PNS to suppress the somatosensory evoked potentials, and subjective complaints of pain associated with noxious laser induced nociception. They additionally found and subsequently postulated that the much lower sensory threshold of A-beta fibers allows selective activation of those fibers in sensory nerves without excitation of A-delta or C fibers. Their study of direct stimulation of the nerve in vivo demonstrated objective evidence of suppression of nociceptive propagation to the central nervous system. This study provided objective and promising evidence for the antinociceptive effects of PNS and may steer future studies regarding peripheral neuromodulation for pain.

As, it has been at times difficult to stimulate mixed sensory and motor nerve without motor recruitment, PNfS, while in its infancy, may be an effective option for local generation of paresthesia. When correctly deployed, PNfS leads in the extremity allow for selective activation of terminal sensory nerve fibers without muscle activation in the gross majority of patients as the subcutaneous adipose tissue insulates the superficial muscle from recruitment. While the exact mechanism of action is still unknown, the dense population of the subcutaneous layer with terminal A-beta fibers and similarity of this to direct peripheral nerve stimulation suggest that the presence of electrical field depolarizes those terminal sensory afferents.

**Patient/Candidate Selection**

Generally speaking, PNS is indicated if the pain lies in the distribution of the peripheral nerve to be stimulated. Peripheral nerve lead deployment has historically placed the patient at higher risk of complication than spinal cord stimulation, and in those difficult situations, SCS is preferred. However, SCS is not without out its own limitations. Placement of an SCS electrode over the dorsal column does present the very serious risk of injury to the cord and infection. Paddle lead placement in the spinal canal is yet more invasive and requires permanent changes to the spinal anatomy and its own attendant surgical and general anesthetic risks. Other limitations to SCS
include lead migration, reduction of effect over time, as well as density and amplitude of paresthesia that is variably dependent upon posture and position. Central stimulation may additionally have difficulty covering many of the ‘high value’ target areas of chronic pain like the feet, craniofacial pain, and in the groin and inguinal region [30]. Complex regional pain syndrome type II, and other specific localized pains also remain difficult to capture with SCS. SCS, and many PNS systems, require placement of an internalized pulse generator or RF receiver and so consideration should be given to the planned placement of the energy source. Placement far from the ultimate neural target requires significant tunneling with associated pain to the patient, risk of infection and in time possible lead strain and fracture especially if crossing a joint or area of stress. Although current implantable pulse generators (IPGs) have diminished in size from their predecessors, they still are large and do require careful planning for placement, and, as such, discussion with the patient should take into account activity level, body habitus to house the IPG, and the ability of the patient to charge and manipulate the system. Further reduction in the size of the IPG will contribute to surgical ease and patient safety. Weiner [31] detailed logical patient selection criteria for PNS below, and much can be extrapolated to the candidate for PNfS:

1. a demonstrated injury for the pain complaint,
2. failure of more conservative treatments and therapies, including surgery (if appropriate),
3. absence of significant drug dependence issues,
4. adequate patient motivation and intelligence,
5. clear understanding that PNS neuromodulation is designed to help control chronic pain but not to cure underlying disease processes,
6. successful trial stimulation,
7. identification of the specific injured and painful nerve using selective nerve/root-blocking techniques.

Nerve root blocks may lack the fidelity of named peripheral nerve, and so when the pain lies wholly in the distribution of a smaller peripheral tributary, a distal local nerve infiltration is preferred. If peripheral nerve field stimulation is to be attempted, blocks may be attempted at the local site at which paresthesia is to be directed. Once the patient has been deemed an appropriate candidate for trialing, significant consideration must be given to the planning of the neuromodulatory array.

Selection of Neuromodulation System

The improved and still improving plasticity of available arrays and generators allows the implanter great fidelity in planning for stimulation, not only in terms of the variety of available neural targets, upstream from the pain, but also the ability of the systems to provide complex programming, steering energy to various electrodes for neuromodulation of subelements of the patient’s individual montage of pain. For example,
a patient with a deeply achy postsurgical knee complaining of concomitant neuropathic anterior leg pain may benefit from a hybrid system providing overlapping paresthesia from any of the following: SCS, L4 nerve root stimulation, direct femoral nerve stimulation or PNfS around the knee or in the region of the infrapatellar branch of the saphenous nerve and the articular branch of the peroneal nerve. Montages of pain change over time and so it is also important to take into account the possibility of pain plasticity as much as possible as revision surgeries add additional cost and risk. Ultimately, it is becoming increasingly common for implanters to meld various elements of the implanted system to meet the various complaints of the patient. PNS was born out of a need to address very specific pain complaints, and hybridization furthers that possibility.

Again it should be the aim of the implanter to provide the densest concordant paresthesia possible via the safest method possible, and so if the pain is readily treatable with spinal cord stimulation, it is preferred, since at present SCS remains the safest modality in most cases. However, if SCS cannot provide adequate coverage or pain relief, or is unsafe or impossible to perform, then PNS or PNfS become reasonable trialing options for the painful extremity. In situations where there is an area of local and definable pain then PNfS may be a consideration. Additionally it should be noted that PNfS, and possibly direct nerve stimulation may provide a degree of additional nociceptive pain relief as opposed to the typical neuropathic pain relief seen in central neuromodulation [27, 29].

Of late, much interest has been directed at possibly increasing limits of electrical field generation by spreading the corresponding electrodes of a circuit across leads as opposed to within the lead. As the corresponding anodal terminal moves away from the cathode it is clear from virtually all electrical modeling research that the anodal and cathodal fields resume independent spherical shapes with little influence upon each other as influence is inversely proportional to the radius to the third power. Little is known about the electrophysiological responses of A-beta sensory terminal afferents to electrical fields at present, but patients routinely report that ‘cross-talking’ generates much larger areas of perceived paresthesia. This may occur because of local effects of the charge in the tissue across wide areas, or it may be a function of cortical mapping and the way the brain understands paresthesia. Lastly, stimulation may influence local hemodynamics, affect neurotransmitter release, increase endorphins and inhibit neuronal depolarization [32].

**Neuromodulation Trial**

It is rare in the surgical realm to be able to reversibly test a proposed modality without significant risk or resources from either the patient or physician, but the percutaneous trial offers this unique ability. The purpose of the trial is multifold. It is a not only a test of the modality and the proposed montage but also of the patient in terms of their...
ability to understand, use and psychologically adapt to the final proposition that their pain is chronic and unremitting but possibly well treated by electricity. While all neuromodulatory trialing should be limited to the minimum amount of time to come to a reasonable conclusion about the therapy’s effectiveness, considerations such as fibrosis (and thus future difficulty in later lead placement) and possible epidural abscess are less of a concern when trialing in the periphery, outside of the spinal canal, and so longer trials may be possible. Longer trialing may be desirous if post-procedural pain clouds the patient’s ability to assess the therapy. Additionally, a longer trial may afford the patient the option to try multiple different electrical stimulation patterns and see how they work. While direct dissection may have up until recently been the standard, ultrasound guidance and nerve stimulation for the insertion of percutaneous electrodes near a peripheral nerve will likely eliminate the need for most open trialing.

For trialing of the patient using both PNfS as well as PNS it is useful for the patient to mark the areas of pain on their own skin with a permanent marker. Dermatographic maps of pain may further inform the surgeon about the type of pain and the intensity of pain from which the patient suffers influencing the selection of neural target. Preoperative planning should additionally include planned skin entry as well as ultimate lead location, and for PNS this may require a sonographic survey of the anatomy.

For PNfS, the size and shape of the area of pain has enormous implications on lead placement, and in the trunk the aim may simply be to bracket the pain. In the periphery, the areas of pain may fall over joints or areas of stress and so lead placement should avoid possible lead strain. This may obviously be a challenge. The lead array should not be placed over the joint line, and the lead should be placed so that the lead body experiences the least tension and repetitive stress with normal skeletal movement. On occasion, strain relief loops placed at the apex of rotation may distribute the stress of repeated flexion and extension over a longer section of lead body. Although during the trial there will be no lead tunneling, the array location and position can only be considered if the planned lead course supports that ultimate array location.

If a small area exists, less than or equal to the area of a credit card, then one lead may be sufficient. If the area of pain is greater, more leads may be required. At present, four leads may be used per generator. The planned incision should be influenced by the axis of the painful area – generally the lead going through the long axis (unless the area of pain is allodynic or has anesthesia dolorosa in which lead placement lies outside the pattern), and so insertion is outside the area of pain. Additionally, the entry should utilize essentially the entire length of the needle available, so that skin entry site and painful area are as far away from each other as possible, as the incision may greatly increase the intensity of the chronic pain and confound the results of the trial. Octopolar arrays provide little additional benefit over quadripolar arrays, and using more contacts per array may limit further montage development. If the area of pain is large or irregular in shape, then the montage requires even more complexity. As noted earlier, the prospect of ‘cross-talking’ electrodes may provide extended areas
of coverage in these situations [33]. Leads should generally be placed on the periphery of the pain, certainly if the area is much greater than the aforementioned credit card, the leads should exist within the peripheral boundaries, and the cross talking will cover the area of pain between leads. Three- and 4-lead arrays have been shown to be effective with this 'cross-talk' approach.

Once the array has been planned, the patient is brought to the operating theatre and draped in customary sterile fashion. Fluoroscopy is used to document the location of the underlying structures and at the conclusion of the case to document lead placement. A universal protocol to all cases in regards to angle (such as true anterior-posterior and/or true lateral) is suggested to simplify replication of lead placement later when planning and performing the permanent implant. Anesthesia varies based on implanters' preference, but most procedures are easily performed with light sedation and a small amount of short acting local anesthesia at the planned incision only. A puncture incision with an 11-blade scalpel is performed prior to introduction of the lead introducer needle. The curvature of the skin and the underlying anatomy have to be appreciated and the needle can be slightly curved to approximate that curvature. Once the needle is ready, it is inserted steeply through the incision and then quickly flattened to parallel the skin. Needle depth is debated among implanters, however there appears to be an overall agreement that too superficial placement will produce cutaneous pain at low amplitudes, and erroneous depth will either require amplitudes too high to produce useful stimulation, or if placed in the muscle, painful muscle recruitment. In some newer devices, a nerve stimulator can help identify the exact target location. When the shaft of the needle is elevated in plane under the skin the needle is easily palpable and the skin tents over the needle and if depressed the skin should barely dimple. If the needle is too superficial then depression will tug on the dermis and dimple it inward. Once the needle has been sufficiently advanced, the stylet is removed and the lead is deployed and the needle withdrawn using a push-pull method analogous to SCS lead deployment. Then intra-operative trialing ensues. Painful stimulation is first addressed by changing electrical configuration and stimulation amplitude. Often the initial sensation is painful, but with increasing amplitude, paresthesia overcomes the painful stimulus. If pain persists, or lack of paresthesia exists, the lead location must be changed. Type of pain informs the correction – deeper or shallower. If the implanter has used too much local anesthetic at the stab wound there is the potential that the needle has pulled the anesthetic deeper and anesthetized the target neural fibers. Occasionally blood or swelling around the lead array will insulate it and on-table trialing becomes impossible. One must simply wait and retest the array, often swelling abates and good paresthesia is felt without lead repositioning. Effort should be made to limit repeat deployments, as increased tissue damage will spoil the trialing results. Programming may vary, but the authors found a simple bipole not only adequate but also sparing in energy use compared to multiple electrode activation with approximately the same results. Different electrodes may be activated and the lead may be withdrawn or carefully advanced as is the authors'
experience that small movements (known as trolling in SCS) may improve the field’s location in respect to larger branches of terminal sensory fibers, thus activating nerves that supply larger territories of skin. Fluoroscopic and radiographic images should document final lead placement. Once the nerves or fibers are appropriately stimulated, the lead is fixed to the skin by direct suturing, silastic anchor, tape or a dermal adhesive. Similar to SCS, care is taken to attend to the patient’s sleeping preferences so as to minimize the impact of the lead on the patient’s body while in repose. The patient is then taken to recovery and reprogramming is undertaken. As mentioned, if swelling or local anesthetic thwarts immediate postplacement programming, one must simply wait for the situation to abate for reattempts. Regardless, the patient will likely need to return the following day as the limits and stimulation parameters will have changed significantly necessitating reprogramming.

Patients who suffer from pain in an extremity within the distribution of a single or possibly two nerves may be better candidates for direct PNS than PNfS. In cases that necessitate direct peripheral nerve stimulation, the deployment of the lead is technically more demanding. Needle stimulators, ultrasound guidance, or both may be used. Prior to consideration of trialing, the patient should undergo appropriate workup and screening. Huntoon and colleagues have spent considerable effort detailing several methods for trialing and implanting peripheral nerves with sonographic guidance. The reader is referred to those papers for additional information [24–26]. Each nerve has preferred loci for stimulation that diminish lead migration and movement. Common neural targets include, but are not limited to the median, ulnar, radial, axillary, suprascapular, brachial plexus, lateral femoral cutaneous, saphenous, sural, peroneal, tibial, sciatic and femoral. Patients should initially undergo trial blockade proximal to the pain with local anesthetic demonstrating at least 80% relief. If surgical intervention is indicated, referral to an orthopedic or neurologic surgeon with familiarity with peripheral nerve surgery must be considered.

Again, preoperative planning is essential as direct nerve stimulation is more complex. Whereas PNfS is concerned with a uniform and single tissue plane and invariable and stationary neural target, PNS arrays and leads cross planes, traveling close to sensitive and often highly mobile structures including the nerves themselves. The patients should only have leads placed while awake and aware and very careful needle advancement is warranted with strict attention to patients’ reports of pain or paresthesia. Delivering uniform charge fields to a nerve is much more challenging in PNS. Whereas intra-electrode resistance is generally static in PNfS and even SCS due to the uniformity of tissue types and relative stability of lead placement, with PNS the presence of multiple tissue types and thus multiple resistances as well as lead movement and dynamic field generation raise the importance of system selection. In situations where impedance is highly variable it may be worthwhile to have systems which provide constant current and variable voltage as they may more readily adapt to the ever changing resistance of the environment. However, understanding the multitude of challenges to the system it is a surprise that most are and remain relatively stable.
over time. As in PNfS the skin should be marked prior to trialing, mainly to force the surgeon run through the technical considerations of the case. Additionally, the process involves the patient in decision-making as well. Ultrasound, being particularly adept in identifying tissue types and fascial planes should be used to identify the nerve as well as the optimal location for lead array and lead body placement. Generally the nerve should be as relatively superficial and as stable as possible. The array location is often best when placed perpendicular to and deep to the nerve, or between the nerve and bone if the nerve closely follows bone as it adds stability to the placement. By placing the array so that it bisects the nerve course in perpendicular fashion the effect of eventual lead migration is minimized. Additionally, needle tract and lead should avoid large vascular branches as well as muscle. Similar to PNfS, considerations are given to lead movement: tunneling and suturing must also be made in PNS even during the trialing phase, as if successful, the permanent implantation must be able to support the lead placement. For example, it may be easy to deploy a small lead to stimulate interdigital nerves but ultimately connecting that lead to a power source may be presently infeasible or quite difficult.

Permanent PNS/PNfS Implantation

Once significant success in capturing and relieving pain with PNS or PNfS is demonstrated with trial lead placement, planning for the permanent implantation of the neuromodulation system ensues. It may be relatively easy to deploy peripheral leads compared with design of and implantation of a PNS system that is both dynamic enough to respond to the movements of the extremities yet durable enough to withstand repeated movement. Most equipment was initially designed to be placed in the central neuroaxis where relatively little movement occurs over time comparing to the often repetitive and extreme movements in the extremities, and so great consideration must be given to reduce the strain on the implanted system.

Body habitus, specifically the amount of adipose tissue available in the extremity, helps determine if the IPG can be implanted there. The patient may lose weight with the additional pain relief as well, and so one must be concerned with changes over time. By peripheral implantation, the surgeon negates the need to cross the shoulder or hip, and this adds to system stability over time; however, if little adipose is available then one defaults to central implantation, either the buttock, lower quadrant of the abdomen, shoulder, pre-cordial region or mid-scapular line/mid-clavicular line. If forced to cross a joint line then one must give consideration not only to the degree of range encountered in the joint, e.g. shoulder greater than elbow, but also to the likelihood of movement and the overall length of the system – array to generator. Sufficient strain relief loop size must be made to allow for incomplete loop closure with ranging movement of the extremity. Extreme extension and or flexion should not tighten the loop to such a degree that a kink appears – if so then all lead flexion will occur at that
one point as opposed to the lead loop length in unison and lead fracture will result. Loop size is inversely proportional to loop strain. Additionally, the loop must fold in the plane of movement, not against it, so that increasing the acuity of flexion angle tightens as opposed to loosens the loop.

While loops allow for freedom of movement, the electrode array must move as little as possible in relation to the neural target. In PNfS, the lead is tied to subcutaneous tissue, often the superficial most fascial plane. If a large anchor is selected, and there is little subcutaneous adipose to protect the skin from the new underlying anchor, the anchor may be buried deep to the first fascial layer, and the fascia closed over the anchor. Erosion may occur if the anchor is too superficial. The implanter has a myriad of choices available for anchoring. Direct ligation-like suturing to the lead is often best. Nurolon (Ethicon Inc.) braided nylon or similar suture is suggested for high strength and integrity over time. With this method, the lead is well secured, the anchor is flat, strong and low-profile, and in a short period of time scar tissue fills the crevices in the stitch and further secures the lead. The suggested method of suturing is the ‘drain stitch,’ similar to that used to secure a chest tube. Challenge may arise, however, if in the event lead revision requires anchor revision, great care must be taken in dissection of the lead from the suture, and this may lengthen the operative time. Low incidence of migration seen with this technique, however, makes up for the increased complexity of the less frequent revisions. Caution must be used to avoid over-tightening the suture on the lead as this may break or deform the lead wires or insulation. To further limit the possibility of migration, the lead should be anchored close to the proximal portion of the array.

Once the lead array is deployed and secured, attention is turned to tunneling over the joint and thus the lead flexion point. At the axis of rotation, dissection to subcutaneous adipose permits the burial of a strain relief loop as described above. The lead loop should not be anchored with permanent suture as unwanted strain may develop in the long term. The lead can be tacked into position using absorbable suture to hold it there while scaring occurs and associated integrity develops. Additionally, in planning the tunneling, it is best to avoid placing the lead over anatomical bony prominences as erosion may occur. Good prior planning, preoperative marking, and attention to detail reward the implanter and patient with stability of the system and thus lasting efficacy.

Common Neural Targets and Treatable Syndromes for PNfS and PNS

Lateral Femoral Cutaneous Nerve and Meralgia Paresthetica
The lateral femoral cutaneous nerve arises from the dorsal roots of L2 and L3, courses through the lateral psoas major muscle, descends into the pelvis crossing the ventral iliacus muscle obliquely and follows the interior of the pelvic girdle anteriorly. It then dives under the inguinal ligament about 1 cm medial and inferior to the anterior
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Superior Iliac Spine

The superior iliac spine then passes inferiorly arising superficial to the hip flexors and then innervates the anterolateral skin of the thigh. Trauma, compression and metabolic disease can injure the nerve. Often well treated by oral or transdermal medical management of pain and or steroid nerve block, occasionally the pain is unremitting and one must consider neuromodulation. Often SCS works well, but the use of PNS has also been shown effective with leads placed based on tissue mapping and or direct nerve stimulation. Ultrasound guidance may be very effective in inserting the electrode in close proximity to the nerve.

Infrapatellar Branch of the Saphenous Nerve and Articular Branch of the Peroneal Nerve at the Knee

Postoperative knee pain is commonly associated with entrapment injuries to the peripheral nerves as they innervate the anterior knee. Durable pain relief has been demonstrated with placement of electrodes in the lateral tissues surrounding the knee. It has been hypothesized that due to the relative superficiality of the nerves, subcutaneous deployment actually depolarizes the nerve in some cases. Care is made not to cross the joint line with the arrays and deployment of four quadripolar leads is best as the electrodes can ‘cross-talk’ to each other generating fields across the knee joint itself. The systems are relatively stable over time. Strain relief is at the knee and tunneling carries leads to the IPG pocket either in the thigh or abdomen. If tunneled to the abdomen, care is taken to avoid crossing the inguinal crease near the lateral femoral cutaneous nerve, so leads are usually lateral to the anterior superior iliac spine.

Tibial Nerve

Involved frequently in entrapment at the tarsal tunnel, crush injuries or trauma, the tibial nerve is easily stimulated at the bifurcation, posterior and proximal to the knee, or better yet, if pain is contained to the foot, at the distal medial calf, posterior to the tibialis posterior tendon and deep to the flexor hallucis longus tendon sheath using an anterior to posterior approach. The tarsal tunnel may be a tempting location as the nerve is easily located, but due to the frequency of entrapment syndromes as a function of tight compression and ligamentous movement the addition of a lead there may be problematic. Multiple mobile structures are in close proximity: in addition to the tibial nerve, there are the posterior tibial artery, tibialis posterior, flexor digitorum longus, and flexor hallucis longus.

Peroneal Nerve

Like the tibial nerve, the peroneal is vulnerable to similar insults. In addition to compression injuries and trauma, chronic peroneal neuropathy can result from peripheral neuropathy, surgical insult from fibular harvest, and athletic conditioning. The peroneal nerve can be stimulated at the sciatic bifurcation immediately proximal to the popliteal fossa, or just below the knee posterior to the fibular head itself. It descends from the bifurcation obliquely along the lateral popliteal fossa to the fibular head and
close to the medial biceps femoris muscle before descending and winding around
the fibular neck next to the peroneus longus before dividing into the superficial and
deep divisions. At the sciatic bifurcation, it may be difficult to selectively stimulate
the peroneal division, and so better exposure and the option of selective stimulation
may exist at the fibular head. The superficial peroneal nerve can be stimulated at the
dorsum of the foot.

Sciatic Nerve
As described above, the bifurcation point of the peroneal and tibial presents a good
site for stimulation. Direct stimulation has additionally been reported at the greater
sciatic notch, dissection to nerve and stabilization of array is difficult however. It is
important to place the array proximal to the insult zone of the nerve. More studies are
needed to evaluate treatment possibilities.

Median, Radial and Ulnar Nerves
Trauma and entrapment of the sensory nerves of the hand and forearm often result in
difficult to treat painful neuropathies. The use of peripheral neuromodulation to treat
the sensory nerves is promising. Median neuropathy may be among the most com-
mon peripheral nerve disorders. The median nerve is easily stimulated at the carpal
tunnel, and new, investigational devices are aimed at this prospect [unpubl. data].
Additionally the median nerve is found in the antecubital fossa medial to the brachial
artery; more proximally it runs with the brachial artery between the biceps brachii
and brachialis muscles. Distal to the crease of the forearm it passes between the two
heads of the pronator teres. The radial nerve can be easily stimulated if a lead is passed
posterior and slightly lateral to the humerus proximal to the elbow, at the distal radial
groove. This may prove to be a stable location. The ulnar nerve is accessed superior to
the medial epicondyle. Again placements deep to the nerve may be more stable over
time. Further research needs to explore lead location and long-term stability.

Axillary and Suprascapular Nerves and the Brachial Plexus
Shoulder hand syndrome and a host of other neuropathic and painful disorders affect
the distributions of the axillary and suprascapular nerves. Regional blocks often pro-
vide excellent but only temporary relief to these areas, and so the prospect of neu-
romodulation as a long-term treatment of pain remains hopeful. Current studies are
evaluating the viability of various treatment options.

Conclusions
PNS and, recently, PNFs are excellent options for the control of extremity pain in
instances where conventional methods have failed and surgical treatment is ruled
inappropriate. New techniques, ultrasound guidance, smaller generators, task-specific
Stimulation of the Peripheral Nervous System


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