Peripheral Nerve Stimulation for the Treatment of Truncal Pain

Kevin D. Cairns\textsuperscript{a} · W. Porter McRoberts\textsuperscript{b} · Timothy Deer\textsuperscript{c}

\textsuperscript{a}Florida Spine Specialists, \textsuperscript{b}Holy Cross Hospital, Fort Lauderdale, Fla., and \textsuperscript{c}Center for Pain Relief, Inc., Charleston, W.Va., USA

Abstract

Neuromodulation practitioners increasingly recognize the potential for peripheral nerve field stimulation (PNfS) to treat pain originating from the trunk. Conditions resulting in truncal pain that may respond to PNfS include cervical and lumbar postlaminectomy syndrome, inguinal neurapraxia, post-herpetic neuralgia, and post-thoracotomy pain. The focus of this chapter is to review the mechanism of action in PNfS, patient selection factors, programming strategies, and technical considerations.

Stimulation of the most distal sensory fibers termed peripheral nerve field stimulation (PNfS) is an emerging area of neuromodulation that has been gaining interest in the treatment of truncal pain. Through the pioneering work of Weiner, Slavin, and Kapural, a resurgence in peripheral nerve stimulation for the treatment of headaches and facial pain has renewed interest in stimulating sensory nerves in the periphery [1–3]. Subcutaneous placement of leads in the region of named nerves in the head and neck has been more recently adapted to placement of leads subcutaneously in the trunk. First described by Paucius for treatment of low back pain after surgery, several case studies have discussed the potential for PNfS in the treatment of truncal pain from the lumbar to the cervical region [4, 5]. The difficulty in directly stimulating named peripheral nerves in the trunk limits the application of direct peripheral nerve stimulation (PNS) for truncal pain; however, stimulation of nerve rootlets in the spinal canal using either an anterograde or retrograde technique has been reported for failed back surgery syndrome, post-herpetic neuralgia (PHN), and ilioinguinal neurapraxia [6]. PNfS is different from the conventional direct PNS first reported in 1976 in that PNfS does not require surgical dissection of an identifiable nerve and thus is not limited by location of named nerves when considering treatment [7]. This chapter will focus primarily on PNfS for truncal pain including mechanism of action,
Mechanism of Action

Similar to spinal cord stimulation (SCS), the exact mechanism of action of PNfS is unknown but most likely occurs through the Gate-Control Theory of Melzack and Wall [8]. Stimulation of large sensory nerves in the periphery was later demonstrated by Wall and Sweet to alleviate pain based on the clinical application of the Gate-Control Theory [9]. Most likely, PNfS alleviates pain by stimulation of A-beta fibers in the subcutaneous layer with subsequent inhibition of A-delta and C fibers (fig. 1). The subcutaneous layer is rich in terminal A-beta sensory terminals and extracellular fluid either in the subcutaneous or subdermal region likely functions as an electrical conduit that facilitates depolarization of these sensory fibers as current follows the path of least resistance. One significant difference between PNfS and spinal cord stimulation is the potential for greater distance between polarities (cathode and anode) in PNfS. Typical SCS contact distances between cathode and anode are less than 10 mm as compared to PNfS distances between cathode and anode being significantly greater.

The authors have implanted PNfS leads subcutaneously in the cervical and lumbar region with polarity distances of over 30 inches with dense paresthesia between contacts. Evoked paresthesia across long distances equates to flow of current across longer distances than traditional SCS with likely depolarization of terminal sensory fibers [10]. The neurophysiologic characteristics of terminal sensory A-beta fibers and the impedance characteristics of the extracellular fluid in the subcutaneous and subdermal layers require different programming strategies than SCS. Electrical stimulation in the subcutaneous region may increase the concentration of local endorphins, affect blood flow, alter neurotransmitters, inhibit cell membrane depolarization and thus inhibit nociceptors similar to transcutaneous electrical nerve stimulation (TENS) and

**Fig. 1.** Lead placement in subcutaneous layer.
temporary percutaneous electrical nerve stimulation (PENS) [7]. Animal studies have suggested that peripheral nerve stimulation may alter the excitation of the central pain processing system thereby alleviating pain [11]. Further work examining the mechanism of action is needed to better understand the neurophysiology and localized changes that occur when current is delivered to the subcutaneous layer (fig. 1).

One potential advantage of PNfS over SCS when treating truncal pain is its ability to target nociceptive pain. Ellrich and Lamp [12] demonstrated that depolarization of the superficial radial nerve significantly decreased laser evoked potentials selectively recording nociceptor stimulation in a group of 15 healthy volunteers. Whether terminal sensory fibers in the subcutaneous region have similar neurophysiologic properties to larger named nerves in the periphery remains to be seen. Given that many pain syndromes targeted in neuromodulation such as FBSS are often mixed pain syndromes, a treatment modality able to potentially target nociceptive pain is advantageous. Treatment of cervical discogenic pain with PNfS as well as disorders not associated with neuropathic pain including abdominal pain further suggest that PNfS may be beneficial as a treatment option for pain of different etiologies [5, 13]. The difficulties of SCS in the long-term treatment of axial back pain are well described and may be related to SCS having a limited ability to treat nociceptive pain as well as the inability of conventional arrays to consistently obtain evoked paresthesia in the trunk [14, 15].

**Patient Selection**

Patients with different pain generators resulting in truncal pain can benefit from PNfS. Patients considered for PNfS trials have failed traditional interventional spinal procedures such as epidural steroid injections, medial branch blocks, facet joint nerve ablations, SI injections, and in many cases surgery. Conditions resulting in truncal pain that have been reported to respond to PNfS are lumbar postlaminectomy syndrome, axial cervical pain, PHN, inguinal pain, ilioinguinal neurapraxia, and post-thoracotomy pain [4, 5, 16, 17]. Direct nerve stimulation in the lateral recess as well as along the nerve roots has also been described for PHN, post-thoracotomy pain, and ilioinguinal neurapraxia. One of the most common diagnoses treated with PNfS is lumbar post-laminectomy syndrome.

**Failed Back Surgery Syndrome**

Among the pain generators implicated after spinal surgery are epidural fibrosis, arachnoiditis, spondylolithesis, junctional stenosis, recurrent disc herniation, central pain, and pseudoarthrosis. Patients with truncal pain after surgery often have few interventional options and PNfS offers a nonpharmacologic option to alleviate pain.
Several case series have suggested that PNfS may be effective for truncal pain after surgery. Paicius et al. [4] first reported a series of 6 patients, 5 of whom had prior lumbar surgery with all patients noting greater than 50% pain relief. Verrills et al. [18] reported that among 13 consecutively implanted patients 85% noted greater than 50% pain relief with a mean follow-up period of 7 months. Although long-term data are not available, Krutsch et al. [19] reported a single patient with lumbar FBSS who had 90% improvement at 12 months postimplant. Report of improvement of discogenic pain after cervical surgery has also been reported with 100% relief of a single patient at 9 months follow-up [5]. Retrograde placement of leads near the lumbar and sacral nerve roots has also been reported as a treatment for patients with FBSS although technical challenges and inability to obtain paresthesia in the low back have limited its widespread use. Lead placement for nerve root stimulation can occur by means of anterograde placement leads in the lateral recess stimulating dorsal roots in the vicinity of the dorsal root entry zone as well as retrograde placement of leads targeting a specific nerve root [6].

General considerations when identifying patients for PNfS after lumbar surgery include integrity of large-fiber sensation in the region of pain, anesthesia dolorosa, presence of hardware, and age of the patient. Identifying anesthesia dolorosa is important as placement of leads lateral to the region of anesthesia dolorosa is imperative. Stimulation directly in the region of anesthesia dolorosa often elicits dysesthesia or an absence of evoked paresthesia both resulting in a poor outcome. Similarly, identification of sensory deficit is important as leads should be placed lateral to the area of hypesthesia rather than directly in the area of hypesthesia. In addition, in patients who have had spinal surgery, the authors have noted that it may be important to take into consideration the presence of hardware as placing leads lateral to the hardware or using additional leads may be of benefit. Younger patients may respond better to PNfS than older patients. In a cohort of 23 patients, those over the age of 60 noted an average pain reduction of 2.83 points on the visual analog scale compared to 4.79 in those younger than 60 [20].

Hybrid systems consisting of placement of PNfS leads in the low back in combination with spinal cord stimulator leads may be beneficial when treating patients who have had lumbar surgery with both back and leg pain. One advantage of hybrid stimulation is the ability to target additional areas of pain as well as potentially being able to address the nociceptive and neuropathic components of pain with PNfS and SCS, respectively. Two case series have described overall improvement of pain with concurrent use of a PNfS and SCS hybrid system [21, 22]. Bernstein et al. [22] reported a series of 20 patients with combination SCS/PNfS systems with the majority of patients preferring the hybrid stimulation (stimulation of both SCS and PNfS leads) to either modality in isolation. Four of the 20 patients in this series initially had implanted SCS systems with significant low back pain following SCS implant and subsequently underwent PNfS implant with significant improvement of low back pain. The authors have performed paresthesia mapping on patients with hybrid systems and have noted
a significant increase in area of evoked paresthesia above the posterior superior iliac spine (PSIS) with PNfS/SCS hybrid stimulation compared to SCS stimulation alone [unpubl. data]. Further studies looking at outcomes of PNfS in combination with SCS based on location of pain, type of lumbar surgery patient underwent, presence of hardware, MRI findings, and type of pain would be beneficial.

Postherpetic Neuralgia

Case reports suggest stimulating different parts of the peripheral nervous system including dorsal rootlets, direct named nerves, and distal sensory fibers in the subcutaneous region may be beneficial for PHN. Upadhyay et al. [23] reported a patient with percutaneous lead placement over the supraorbital nerve with 100% pain relief in a 55-year-old male with PHN following a vesicular eruption involving distribution of the supraorbital nerve. Dunteman [24] reported less robust results while treating PHN with direct nerve stimulation with mild improvement in less than half of the patients when placing percutaneous leads near the named nerves. Yakovlev and Peterson [25] reported a case of leads placed subcutaneously in an individual with truncal pain involving the right posterior chest wall due to intractable PHN with 100% relief 6 months postimplantation with significant improvement in function. Lead placement along the lateral recess of the spinal canal stimulating dorsal roots has also been reported. The authors originally used this technique for truncal PHN with mixed results and have evolved their approach for PHN to consist of a hybrid system with a single 8-contact lead placed at the lateral recess of the spinal canal corresponding to dermatome of involvement and two 4-contact subcutaneous leads bordering the area of pain in the posterior trunk to maximize chances of a successful trial. PHN may occur from one of three mechanisms: damage to A-delta and C fibers with collateral sprouting occurring from A-beta sensory fibers to nociceptors causing hyperalgesia and allodynia, loss of both large and small neural fibers causing anesthesia dolorosa resulting in hyperpathia and an absence of sensation, and peripheral sensitization with hyperactive primary sensory fibers causing allodynia with primarily intact sensation. Whether choosing a neuromodulation therapy to target different parts of the peripheral nervous system based on the underlying pathophysiologic mechanism in a particular disease syndrome results in different outcomes remains to be seen.

Inguinal Neuropraxia

Approximately 1–2% of patients that undergo hernia surgery have complications of neuralgia that account for the majority of patients with chronic inguinal pain. Stinson et al. [17] reported a case series of 3 patients who noted 75–100% reduction in pain
with subcutaneous placement of two 8-contact leads bordering the hernia incision. Interestingly, 1 of the 3 patients had previously failed retrograde placement along the course of the T12 and L1 nerve roots despite 100% evoked paresthesia in the region of pain suggesting the importance of considering different neural targets in neuro-modulation. Aló et al. [6] reported successful treatment of ilioinguinal neuropraxia after multiple surgeries with retrograde placement of two 4-contact leads implanted along the T12 and L1 nerve roots. The patient noted painful stimulation initially with a guarded cathode stimulation which improved with a triple cathode and one anode program suggesting the importance of different programming strategies in PNS.

Post-Thoracotomy Pain

PNfS has also been reported for the treatment of post-thoracotomy pain in 2 patients with greater than 50% pain relief and reduced need for pain medications [26]. The authors have combined placement of leads in the lateral recess and subcutaneous region in patients with post-thoracotomy pain with mixed results.

PNfS Technical Considerations

Proper placement of PNfS leads for truncal pain relief requires attention to two fundamental details: lead depth and lead positioning in relation to region of maximal pain. Lead placement in the subcutaneous layer is imperative for proper stimulation of the terminal sensory fibers. Superficial placement of PNfS leads often results in painful dysesthesia noted by patients as a burning and stinging sensation at low sensory thresholds. Placement too deep may result in the lead being inserted into muscle tissue or too far away from terminal sensory afferents to recruit at low energies with patients noting an absence of evoked paresthesia. The subcutaneous layer has the highest density of terminal sensory A-beta afferents and more recently Falco et al. [10] have shown that the subcutaneous layer is amenable as an electrical conduit to create electrical circuits of long distances thereby potentially allowing depolarization of terminal sensory afferents over larger areas.

Most practitioners implant percutaneous 4-contact or 8-contact leads by palpating the distal aspect of the Tuohy needle with advancement to ensure the needle being at the correct depth and also to maintain uniformity in depth. One case has been reported whereby a paddle lead was implanted in the lumbar subcutaneous region following unsuccessful permanent implantation of percutaneous leads with a reported improvement in pain reduction [27]. The advantages of percutaneous lead over paddle during PNfS trial for truncal pain include ease of placement whereby intraoperative stimulation may be performed, circumferential stimulation allowing potential recruitment of additional terminal sensory fibers, ability to minimize local
anesthetic minimizing inhibition of sensory fibers during intraoperative stimulation, and wider spacing of contacts within a lead. One potential advantage of paddle lead is the ability to direct stimulation away from the skin minimizing stimulation of A-delta fibers that may cause dysesthesia and ability to potentially target current towards deeper pain generators. The authors prefer percutaneous leads and a ‘tenting technique’ whereby posterior pressure is applied allowing better separation of the dermal layers from the underlying fascia. Our technique for trial implantation of PNfS leads in the lumbar spine is accomplished in the following manner. The day before both trial and permanent implantation, patients are instructed to mark the area of maximal pain either by marking the region of worst pain or by rating different areas on a scale from zero to ten. On the day of the procedure, this area again is confirmed by palpating the area of pain and having the patient rate the pain from zero to ten. The authors have found this is best accomplished by palpating from outside the region of pain moving centrally and marking the numeric rating scale (NRS) scores directly on the patient (fig. 2). If a patient has pain with certain activities such as walking, standing, etc., they are asked to perform that task to ensure the area of pain is clearly identified. In addition, pinprick sensory testing is performed and attention is paid to whether the patient has signs of allodynia. If allodynia or hypesthesia is noted, the leads are placed just outside of this region. It is the authors’ experience that anesthesia dolorosa does not respond to lead placement directly in the area of anesthesia dolorosa but bordering it. The authors have also noted that placing leads at further distances apart is preferable to shorter distances as well. Care must be taken to avoid placing leads over bony protuberances such as the PSIS region which may later cause lead erosion through the skin or placement of leads over the ischium for the same reason.

After prepping and draping the patient in usual sterile fashion a skin wheal is raised 3.5 inches away from the region of maximal pain (noted as a circle in fig. 2). Careful attention is made to minimize the amount of local anesthetic (typically 1–1.5 ml of 1% lidocaine mixed with epinephrine) to avoid spread of anesthetic to the leads that
may inhibit the patient's perception of paresthesia upon intraoperative trial stimulation. Leads may be staggered to maximize total area of coverage.

Using an 11-blade scalpel, a puncture incision (approximately 5 mm) is made to minimize tissue disruption and the curved Tuohy needle is advanced through the incision. A loss of resistance signifies entrance into the subcutaneous space. The operator then grips the needle hub between the thumb and the index and middle fingers and applies slight posterior pressure. This creates a 'tenting' of the tissue as the distal portion of the needle is raised below the skin surface (fig. 3, 4).

The operator's free hand is used to palpate the skin surface and assess advancement of the needle as denoted by the tenting of the skin. When properly performed, minimal resistance is noted as the tip of the needle is advanced subcutaneously. If there is substantial resistance to advancement of the needle and if skin dimpling is produced, than the lead is in the skin and therefore too superficial and the needle is redirected into a deeper plane. If the needle cannot be palpated, it is too deep in the subcutaneous tissues, and would then be redirected superficially. The stylet is then removed from the introducer needle and the lead is advanced through the needle and the needle is withdrawn over the lead prior to performing intraoperative stimulation.

After performing intraoperative stimulation, the leads are secured to the skin either with an anchoring device or by suturing directly to the lead.

Carayannopoulos et al. [28] describe an ultrasound guided technique for placement of PNS leads for ilioinguinal neuralgia. By visualizing the targeted nerve, a percutaneous approach for placement of trial leads was possible limiting the tissue trauma associated with direct nerve stimulation and allowing parallel placement of electrodes to the targeted nerve. The authors have examined PNIS leads postimplantation with ultrasonography but have not used it as a tool to aid in lead placement. One challenge the authors have identified in placement of leads at a specific depth is that the subcutaneous layer thickness varies as a function of the patient's body mass index. Therefore, ultrasound-guided techniques may best be utilized by identifying different layers rather than placement of the leads at a specific depth given these differences.
Programming for PNfS systems is dramatically different from SCS given the differences in the target neural element and different impedance characteristics of the subcutaneous layer compared to the epidural space. Earlier programming techniques used by the authors coupled the two related polarities on the same lead and also using multiple cathodes and anodes on the same lead. Both conventional PNfS programming techniques demanded higher energy requirements for paresthesia and pain relief. In addition, like other implanters, the authors found that by limiting polarities on the same lead the maximum area that could be treated was approximately the size of two business cards. As a result, the authors developed more sophisticated programming techniques which they have found to reduce energy requirements and larger area of paresthesia resulting in better pain relief. Two common programming strategies used by the authors include triple anode single cathode (3A1C) and wide-spaced cross talk stimulation.

Wide-spaced cross-talk programming refers to an electrode array construct with significantly greater distances between polarities (cathode and anode) on different leads. In a group of 18 patients with chronic pain that were implanted with PNfS systems using a wide-spaced cross-talk programming, patients noted significant pain relief and reduction in pain medications [10] (fig. 5).

Compared to conventional programming involving a cathode/anode array on the same lead where patients note more specific pinpoint stimulation, patients with wide-spaced arrays report a more diffuse ‘flow sensation’ from one polarity to the other. In general, patients note less painful dysesthesia with wide-spaced arrays with less biting and burning sensation and a larger area of paresthesia compared to conventional programming (polarities on the same lead) and improved pain relief [authors’ unpubl. data]. In addition, with lower energy requirements patients better tolerate the stimulation as the incidence of dysesthesia that may occur from activation of painful a delta and c fibers may be minimized. Greater area of paresthesia appears
to be generated with lower energy requirements using the wider spacing of related polarities.

Triple-anode single-cathode (3A1C) is a novel programming strategy used to create a large area of paresthesia with four-lead PNS systems. Patients are programmed with four, interleaved stimulation sets each comprising of a single cathode with three anodes: all active electrodes on separate leads. This generates a large area of

Fig. 6. Four-quattrode lead 3A1C programming array.
paresthesia. Programming parameters consist of frequencies of 30 Hz and a pulse width of 200. Patients with 3A1C programming typically report significant pain relief with the use of anodes and cathodes on leads separate from each other resulting in a larger area of paresthesia and improved pain relief than with conventional (cathode and anode on the same lead) programming with an implanted PNfS system (fig. 6).

Patients often report the area between electrodes as one solid area of paresthesia as opposed to four distinctly different and thus smaller areas of paresthesia. Paresthesia does not appear to be diluted as area increases, however increased power is required. The use of an interleaved three anodes and a single cathode array may be a beneficial programming option for patients implanted with four-lead PNfS systems. We hope to encourage clinicians to explore these novel programming technique in hope of achieving a comfortable paresthesia overlap and pain relief for their patients. The need for four peripheral nerve leads appears to be substantiated. Future research is needed regarding the limits of interelectrode distance, the areas of paresthesia generated, the density of paresthesia generated, the pain relief within the paresthesia, the type of pain which is controlled: neuropathic, nociceptive or both, the relation of the paresthesia to the programmed array, e.g. area vs. linear arrays.

References


Timothy Deer, MD
The Center for Pain Relief, Inc.
400 Court Street, Suite 100
Charleston, WV 25301 (USA)
Tel. +1 304 347 6141, Fax +1 304 347 6855, E-Mail DocTDeer@aol.com

Stimulation for Truncal Pain 69