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Ultrasound-Guided Percutaneous Peripheral Nerve Stimulation for Postoperative Analgesia: Could Neurostimulation Replace Continuous Peripheral Nerve Blocks?

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T he moderate-to-severe pain many patients experience after orthopedic surgery is often treated with opioids, which are associated with undesirable adverse effects such as nausea, vomiting, sedation, and respiratory depression. Potent site-specific analgesia with far fewer adverse effects may be provided with a continuous peripheral nerve block.1–3 Unfortunately, perineural infusion has yet to be reliably inserted approximately 0.5 to 3.0 cm remote from a peripheral nerve.4–6 This technique is often “effective, but unrealistic”; and calls within the surgical literature to abandon continuous peripheral nerve blocks.6,7 There is new evidence that suggests an analgesic alternative—ultrasound-guided percutaneous peripheral nerve stimulation (pPNS)—holds promise to provide postoperative analgesia free of many of the major limitations of both opioid analgesics and continuous peripheral nerve blocks.

The concept of using electrical stimulation to induce analgesia is hardly new: the ancient Romans prescribed contact with a living torpedo fish—able to deliver up to 220 V of current—as an analgesic;8 and this technique continued to be recommended through the Middle Ages up until at least the 16th century for a wide variety of pain-inducing ailments.9 Electroanalgesia continued to evolve through the 18th century with the discovery of artificial means to produce electrical current,10 with the first device specifically designed for this purpose—the “Electreat”—produced in the early 1900s.10 Subsequently, the first implantable spinal cord stimulator was described in 1967, with the first implantable peripheral nerve stimulator following a year later.11

MECHANISM OF ACTION

Although multiple theories exist for the mechanism of action of peripheral nerve stimulation for the treatment of pain,11 it is most commonly explained using the “gate control theory” of Melzack and Wall.12 The theory elucidates how electrical current-induced activation of large-diameter myelinatedafferent peripheral nerve fibers inhibits transmission of pain signals (the “gate”) from small-diameter pain fibers to the central nervous system at the level of the spinal cord.12,13 Wall and Sweet14 proposed inducing analgesia by stimulating primary afferent neurons, and, soon after, commercially available stimulation systems were used (frequently off-label) to deliver peripheral nerve stimulation.15 In the following decades, the efficacy of neurostimulation was demonstrated in the management of chronic pain states with the use of surgically implanted spinal cord and peripheral nerve stimulators.16,17

However, the application of neurostimulation to postoperative pain states has been limited by the invasive nature of the available electrical leads: conventional units typically require multiple electrodes in close proximity to the peripheral nerve that require invasive and time-consuming surgery to place.18 In addition, these procedures require surgical reversal with removal of the leads, frequently complicated due to fibrous capsule formation adherent to the target nerve.19 Stimulation with electrodes placed on the skin (transcutaneous electrical nerve stimulation) has been investigated previously to determine if it has the potential to avoid these limitations.20,21 However, activation of pain fibers in the skin can greatly limit the degree of tolerated current that can be delivered by transcutaneous electrical nerve stimulation and often creates an undesirable analgesic “ceiling.”22,23

To enable application of neurostimulation for the treatment of postoperative pain, optimally an analgesic modality should be administered without requiring an open surgical incision. Extremely small, insulated electrical leads have been developed that permit relatively rapid percutaneous insertion through a needle.24,25 When combined with ultrasound guidance, a lead may be reliably inserted approximately 0.5 to 3.0 cm remote from a peripheral nerve using similar landmarks and general approach as for perineural catheter placement.26–28 Ultrasound-guided pPNS was first reported in situ by Huntoon and Burgher29 in 2009 using an epidural neurostimulation electrode for the treatment of chronic neuropathic pain. Although similar techniques were subsequently reported for additional chronic pain conditions,29–31 it had yet to be applied to a postoperative pain state.

APPLICATION TO POSTOPERATIVE PAIN

Recently, preliminary data described the use of pPNS to treat pain after total (tricompartment) knee arthroplasty in 11 subjects.32–34 In 2 of these abstracts,32,33 a total of 10 individuals were included who experienced postoperative knee pain difficult to control with oral analgesics between 6 and 97 days after surgery. Using ultrasound guidance, a femoral and/or sciatic nerve electrical lead was inserted, depending on where most of the pain originated (anterior vs posterior). Of these 10 subjects, 5 had complete resolution of their pain at rest, 4 experienced a 57% to 67% alleviation of their pain at rest, and 1 did not experience an improvement in pain at rest. The number of patients who were included limits the strength of the research, and the potential for improved pain at rest is promising. Ultrasound-guided pPNS may be a viable option to control postoperative pain after total knee arthroplasty.
decrease, and I only a 14% reduction. Dynamic pain during both passive and active range of motion exercises was reduced an average of 28%, although neither maximum passive nor active knee range-of-motion was consistently improved. An additional case report described one patient who had both femoral and sciatic leads placed which resulted in a reduction of pain from a 3 to a 2 on a 0 to 10 numeric rating scale. On postoperative day 2, this subject was discharged home with the lead/stimulator unit in situ, and his electroanalgesic therapy continued until the leads were removed 43 days after surgery—approximately 2 months after their initial insertion.

**DISCUSSION**

In the setting of the population health risks related to prescription opioids and the logistical limitations of continuous local anesthetic infusions, novel and effective techniques to improve the acute pain experience would be both timely and important. The confluence of 4 relatively recent developments may now permit the wide application of pPNS to treat postoperative pain: (1) the proliferation of accessible ultrasound machines, (2) the high prevalence of anesthesiologists with skills in ultrasound-guided regional anesthesia, (3) the development of a stimulator small enough to be adhered to the skin, and (4) the development of an insulated electrical lead specifically designed for percutaneous, extended use (up to 60 days) in the periphery.

With the limited available data and no direct comparisons, we can only speculate on the pain reduction provided by pPNS versus continuous peripheral nerve blocks. Unlike continuous peripheral nerve blocks, pPNS theoretically induces no proprioception, motor, or sensory deficits, permitting unconstrained participation in physical therapy and decreasing the possibility of an increased risk for fracture, migration, dislodgement, and infection, permitting a dramatically long duration of lead retention—in some cases, well over a year.37–39 The footprint of new electrical generators are so small they may be adhered directly to the patient, thus avoiding the challenges of heavy local anesthetic reservoirs and portable infusion pumps.34 Combined, these characteristics permit a far longer duration of use for pPNS compared with continuous peripheral nerve blocks, possibly providing both preoperative and subsequently postoperative analgesia that outlasts the pain resulting from nearly all surgical procedures. In addition, there are no risks of local anesthetic leakage or toxicity, the latter allowing the concurrent use of multiple leads. Also notable is that leads may be inserted with minimal concern of fascial planes between the uninsulated tip and target nerve because fascia impedes electrical current far less than local anesthetic. Because the theoretical optimal lead location is relatively remote from target nerves—between 0.5 and 3.0 cm—there is the possibility of easier/faster insertion, lower incidence of failure, and perhaps even a decreased risk of nerve injury.

There are noteworthy limitations of ultrasound-guided pPNS, the first of which is that there are currently no commercially-available temporary and reversible leads purposely designed for extended percutaneous use cleared or approved by the US Food and Drug Administration specifically for acute pain within the peripheral nervous system (although one system recently received Food and Drug Administration 510(k) clearance for use up to 30 days in the back and/or extremities for the symptomatic relief of chronic, intractable pain and acute pain, including postsurgical and posttraumatic pain, but is not yet commercially available).30,31 A second concern is that the specific lead used for the described cases has a 7.5% fracture rate of the terminal anchor during removal when used for the treatment of pain (Joseph Boggs, PhD, personal communication, October 6, 2015). Lastly, although neurostimulation has previously been described involving nearly every major peripheral nerve, it remains undetermined how effective pPNS will be for the treatment of acute pain in anatomic locations other than the femoral and sciatic areas.

Robust clinical trials examining important outcome metrics such as pain experience, functionality, health care expenditure, hospital length of stay, and incidence of adverse events will be needed to assess whether this technology can provide value in the management of acute postoperative pain. We believe that pPNS has the potential to completely revolutionize postoperative analgesia—and, specifically, regional anesthesia/analgesia—as it has been practiced using local anesthetics and medication adjuvants for the past century.39

**REFERENCES**

1. Ilfeld BM. Continuous peripheral nerve blocks: a review of the published evidence. *Anesth Analg*. 2011;113:904–925.
2. Ilfeld BM. Continuous peripheral nerve blocks: an update of the published evidence and comparison with novel, alternative analgesic modalities. *Anesth Analg*. 2016 In press.
3. Ilfeld BM, Duke KB, Donohue MC. The association between lower extremity continuous peripheral nerve blocks and patient falls after knee and hip arthroplasty. *Anesth Analg*. 2010;111:1552–1554.
4. Capdevila X, Bringuier S, Borgeat A. Infectious risk of continuous peripheral nerve blocks. *Anesthesiology*. 2009;110:182–188.
5. Rawal N. American Society of Regional Anesthesia and Pain Medicine 2010 Gaston Labat Lecture: perineural catheter analgesia as a routine method after ambulatory surgery—effective but unrealistic. *Reg Anesth Pain Med*. 2012;37:72–78.
6. Kandasani M, Kinmimomath AW, Sarungi M, Baines J, Scott NB. Femoral nerve block for total knee replacement—a word of caution. *Knee*. 2009;16:98–100.
7. Feibel RJ, Dervin GF, Kim PR, Beaulé PE. Major complications associated with femoral nerve catheters for knee arthroplasty: a word of caution. *J Arthroplasty*. 2009;24:132–137.
8. Tsoucalas G, Karamanou M, Lymperi M, Gennimata V, Androutsos G. The “torpedo” effect in medicine. *Int Marit Health*. 2014;65:65–67.
9. Stillings D. A survey of the history of electrical stimulation for pain to 1900. *Med Instrum*. 1975;9:255–259.
10. Gildenberg PL. History of electrical neuromodulation for chronic pain. *Pain Med*. 2006;7:S7–S13.
11. Guan Y. Spinal cord stimulation: neurophysiological and neurochemical mechanisms of action. *Curr Pain Headache Rep*. 2012;16:217–225.
12. Melzack R, Wall PD. Pain mechanisms: a new theory. *Science*. 1965;150:971–979.
13. Campbell JN, Taub A. Local analgesia from percutaneous electrical stimulation. A peripheral mechanism. *Arch Neurol*. 1973;28:347–350.
14. Wall PD, Sweet WH. Temporary abolition of pain in man. *Arch Neurol*. 1973;28:347–350.
15. Long DM. Electrical stimulation for relief of pain from chronic nerve injury. *J Neurosurg*. 1973;39:718–722.
16. Deer TR, Mekhail N, Provenzano D, et al. The appropriate use of neurostimulation of the spinal cord and peripheral nervous system for the treatment of chronic pain and ischemic diseases: the Neuromodulation Appropriateness Consensus Committee. *Neuromodulation*. 2014;17:515–550.
17. Deer TR, Mekhail N, Petersen E, et al. The appropriate use of neurostimulation: stimulation of the intracranial and extracranial space and head for chronic pain. *Neuromodulation Appropriateness Consensus Committee. Neuromodulation*. 2014;17:551–570.
18. Hassenbusch SJ, Stanton-Hicks M, Schoppa D, Walsh JG, Covington EC. Long-term results of peripheral nerve stimulation for reflex sympathetic dystrophy. *J Neurosurg*. 1996;84:415–423.

19. Picaza JA, Hunter SE, Cannon BW. Pain suppression by peripheral nerve stimulation. Chronic effects of implanted devices. *Appl Neurophysiol*. 1977;40:223–234.

20. Hymes AC, Raab DE, Yonehiro EG, Nelson GD, Pinty AL. Electrical surface stimulation for control of acute postoperative pain and prevention of ileus. *Surg Forum*. 1973;24:447–449.

21. VanderArk GD, McGrath KA. Transcutaneous electrical stimulation in treatment of postoperative pain. *Am J Surg*. 1975;130:338–340.

22. Yu DT, Chae J, Walker ME, Hart RL, Petroski GF. Comparing stimulation-induced pain during percutaneous (intramuscular) and transcutaneous neuromuscular electric stimulation for treating shoulder subluxation in hemiplegia. *Arch Phys Med Rehabil*. 2001;82:756–760.

23. Yu DT, Chae J, Walker ME, Fang ZP. Percutaneous intramuscular neuromuscular electric stimulation for the treatment of shoulder subluxation and pain in patients with chronic hemiplegia: a pilot study. *Arch Phys Med Rehabil*. 2001;82:20–25.

24. Deer TR, Levy RM, Rosenfeld EL. Prospective clinical study of a new implantable peripheral nerve stimulation device to treat chronic pain. *Clin J Pain*. 2010;26:359–372.

25. Huntoon MA, Hoelzer BC, Burgher AH, Hurdle MF, Huntoon EA. Feasibility of ultrasound-guided percutaneous placement of peripheral nerve stimulation electrodes and anchoring during simulated movement: part two, upper extremity. *Reg Anesth Pain Med*. 2008;33:558–565.

26. Huntoon MA, Huntoon EA, Obray JB, Lamer TJ. Feasibility of ultrasound-guided percutaneous placement of peripheral nerve stimulation electrodes in a cadaver model: part one, lower extremity. *Reg Anesth Pain Med*. 2008;33:551–557.

27. Monti E. Peripheral nerve stimulation: a percutaneous minimally invasive approach. *Neuromodulation*. 2004;7:193–196.

28. Huntoon MA, Burgher AH. Ultrasound-guided permanent implantation of peripheral nerve stimulation (PNS) system for neuropathic pain of the extremities: original cases and outcomes. *Pain Med*. 2009;10:1369–1377.

29. Rauck RL, Kapural L, Cohen SP, et al. Peripheral nerve stimulation for the treatment of postamputation pain—a case report. *Pain Pract*. 2012;12:649–655.

30. Rauck RL, Cohen SP, Gilmore CA, et al. Treatment of post-amputation pain with peripheral nerve stimulation. *Neuromodulation*. 2014;17: 188–197.

31. Deer T, Pope J, Benyamin R, et al. Prospective, multicenter, randomized, double-blinded, partial crossover study to assess the safety and efficacy of the novel neuromodulation system in the treatment of patients with chronic pain of peripheral nerve origin. *Neuromodulation*. 2016;19:91–100.

32. Ilfeld BM, Gilmore CA, Grant SA, et al. Ultrasound-guided percutaneous peripheral nerve stimulation for postoperative analgesia following total knee arthroplasty: a prospective feasibility study. *J Orthop Surg Res*. In Press.

33. Ilfeld BM, Grant SA, Gilmore CA, et al. Neurostimulation for post-surgical analgesia: a novel system enabling ultrasound-guided percutaneous peripheral nerve stimulation. *Pain Practice*. In Press.

34. Grant SA, Ilfeld BM, Martin G, et al. Percutaneous peripheral nerve stimulation for the treatment of perioperative pain during total knee arthroplasty [Abstract]. *Reg Anesth Pain Med*. 2016;A1542.

35. Ilfeld BM. Single-injection and continuous femoral nerve blocks are associated with different risks of falling. *Anesthesiology*. 2014;121:668–669.

36. Ilfeld BM, Gabriel RA, Saulino MF, et al. Infection rate of electrical leads used for percutaneous neuromuscular stimulation of the peripheral nervous system. *Pain Practice*. In Press.

37. Marsolais EB, Kobetic R. Implantation techniques and experience with percutaneous intramuscular electrodes in the lower extremities. *J Rehabil Res Dev*. 1986;23:1–8.

38. Shimada Y, Matsunaga T, Misawa A, Ando S, Itoi E, Konishi N. Clinical application of peroneal nerve stimulator system using percutaneous intramuscular electrodes for correction of foot drop in hemiplegic patients. *Neuromodulation*. 2006;9:320–327.

39. Onders RP, Elmo M, Khansaririna S, et al. Complete worldwide operative experience in laparoscopic diaphragm pacing: results and differences in spinal cord injured patients and amyotrophic lateral sclerosis patients. *Surg Endosc*. 2009;23:1433–1440.

40. van Zundert A, Helmstädt A, Goerig M, Mortier E. Centennial of intravenous regional anesthesia. Bier's Block (1908–2008). *Reg Anesth Pain Med*. 2008;33:483–489.