DARING DISCOURSE

Ultrasound-Guided Percutaneous Peripheral Nerve Stimulation for Postoperative Analgesia

Could Neurostimulation Replace Continuous Peripheral Nerve Blocks?

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The 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.[1,2] Unfortunately, perineural infusion has its own set of limitations such as inducing motor, sensory, and proprioception deficits that possibly increase the risk of falling[3]; limited duration due to the risk of infection[4]; and, for ambulatory patients, the burden of carrying an infusion pump and local anesthetic reservoir. These, among other, limitations have led some leaders in regional anesthesia to conclude that this technique is often "effective, but unrealistic"[5]; 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,[9] 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.[10]

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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 myelinated afferent 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 Sweet[14] 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]

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.[23,24] 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.[25–27] Ultrasound-guided pPNS was first reported in situ by Huntoon and Burgher[28] 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%

decrease, and 1 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.[34] 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 of falling.[3,35] Helically coiled leads theoretically minimize the risks of fracture, migration, dislodgement, and infection,[36] 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.[24] 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 of 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 consumption, 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.[40]

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