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Radiofrequency Probe Guidance in Peripheral Nerve Stimulator Placement for Complex Anatomy: A Case Report

Komal Luthra, MD[1], Ankur Jain, DO[2], Yousef Darwish, MD[1], Pranamya Suri, MD[1], and Akhil Chhatre, MD[1]

Background: Peripheral nerve stimulation (PNS) has been recognized for its efficacy in treating various pain conditions. However, its application in anatomically unique patients, especially those with achondroplasia, is not well established.

Case Report: We describe a 30-year-old woman with achondroplasia suffering from neuropathic pain after total knee arthroplasty. Due to inadequate pain control from standard pharmacotherapy, she underwent PNS. Sensory stimulation was performed utilizing a radiofrequency ablation (RFA) probe to precisely locate the target sensory nerve. Once the correct sensory nerve was identified, the trajectory of the lead placement was adapted to the patient's anatomical features. The modified PNS implantation technique using RFA probe guidance resulted in substantial pain relief, reduction of opioid consumption, and no procedural complications.

Conclusions: The positive outcomes observed in this case underscore the potential for this innovative approach to be considered for use in those with variable anatomical challenges.

Key words: Achondroplasia, total knee arthroplasty, neuropathic pain, peripheral nerve stimulation, chronic pain

BACKGROUND

Peripheral nerve stimulation (PNS) is an advanced neuromodulation technique used to manage chronic pain by delivering electrical impulses to specific peripheral nerves. Since the inception of the gate control theory in 1967, this method has recently regained recognition as an effective alternative to traditional conservative treatments, offering significant pain relief with a favorable safety profile (1-3). The procedure involves implanting helically coiled electrical leads near the peripheral nerves, which are connected to a pulse generator (4). These electrical impulses modulate neural activity by stimulating large-diameter myelinated afferent nerve fibers, disrupting pain signals at the spinal cord level, and providing relief for a range of conditions, such as neuropathy, complex regional pain syndrome, acute postoperative pain, poststroke shoulder pain, back pain, pelvic pain, and cluster headaches (4-7).

Despite its potential benefits, PNS presents several challenges, particularly in the accurate placement of the leads near the targeted peripheral nerves. The leads are typically placed at a distance of 0.5 cm to 3.0 cm from the target nerve under ultrasound or fluoroscopic-guidance (4,8). Traditional methods of lead placement rely on anatomical landmarks, which may be imprecise and unreliable due to the inherent variability in individual anatomy. These variations can result in significant differences in nerve location and pathway, making it challenging to achieve consistent results across different patients (9). This imprecision can lead to suboptimal positioning, reducing the effectiveness of the therapy and sometimes necessitating repositioning. While repositioning the needle, the electrical impulses generated by the PNS device can inadvertently stimulate nearby motor fibers, causing involuntary and painful

From: [1]Johns Hopkins University School of Medicine, Department of Physical Medicine & Rehabilitation, Baltimore, MD; [2]Ocean University Medical Center, Brick Township, NJ

Corresponding Author: Akhil Chhatre, MD, E-mail: achhatr1@jhmi.edu
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muscle contractions. Consequently, precise lead placement is crucial for maximizing therapeutic outcomes and minimizing adverse effects, including neurologic injury and procedural complications during placement, such as pain and discomfort (10).

Another treatment modality for chronic pain patients utilizes radiofrequency ablation (RFA). The technique used during placement of the RFA probe offers a potential solution to the challenges mentioned during PNS placement. While PNS primarily relies on electrical stimulation of peripheral nerves to modulate pain, RFA works by using heat generated by RF waves to ablate specific nerve fibers, offering a more targeted approach (11,12). RFA utilizes a smaller and more focused field of stimulation, which minimizes the risk of aberrant contractions by more precisely targeting specific nerve fibers. By applying principles of RFA to PNS, it is possible to enhance the accuracy of lead placement, ensuring optimal contact with the targeted nerve fibers and improving procedural and clinical outcomes. This case report explores the integration of RFA techniques with PNS procedures, proposing a novel approach that leverages the precision of RFA for better placement of PNS leads. This innovative method aims to enhance the efficacy of PNS, providing more consistent and effective pain relief for patients with chronic pain conditions.

Unique anatomical variations are observed in patients with achondroplasia, where significant anatomical variability often complicates the accurate placement of PNS leads. The characteristic features of achondroplasia, such as shortened limb length, altered bone morphology, and disproportionate skeletal growth, result in atypical nerve pathways and the abnormal positioning of neurovascular structures (13). Specifically, the femur and other long bones are not only shorter but may also present with angular deformities, further displacing the expected anatomical location of peripheral nerves. These skeletal abnormalities, combined with the reduced soft tissue mass surrounding the nerves, create a limited and challenging space for the precise placement of neuromodulation devices.

CASE PRESENTATION

A 30-year-old woman with achondroplasia with chronic neuropathic pain following right total knee arthroplasty (TKA) presented to our pain clinic. The institutional policy did not require formal informed consent for this deidentified case report. She experienced severe limitations in functional capacity, exacerbated sleep disturbances, and escalation of depressive symptoms. Based on initial evaluation, her symptoms were attributed to common peroneal nerve neuropathy. A multimodal regimen, including anti-inflammatories, gabapentin, pregabalin, and duloxetine provided inadequate pain relief. Additionally, the patient underwent a right proximal peroneal nerve pulsed RF followed by RFA twice, providing only temporary relief. The lack of sufficient pain relief from previous treatments necessitated the consideration of an alternative approach, such as PNS. Achondroplasia presents significant challenges for PNS lead placement due to short limb stature and limited anatomical space for internal stimulator placement (13).

The patient's pain was located in the lateral aspect of the lower right leg, consistent with the dermatomal distribution of the peroneal nerve. The patient's initial electromyography and nerve conduction study, in 2019, did not reveal any evidence for focal neuropathy or lumbosacral plexopathy. In 2021, the patient underwent a right common peroneal nerve block and experienced 100% pain relief immediately after the procedure. The common peroneal nerve, also known as the common fibular nerve, is a branch of the sciatic nerve responsible for sensory input to the anterior and lateral regions of the leg and foot, as well as motor innervation in the lower extremity. Its anatomical course runs along the posterolateral aspect of the thigh, passing beneath the long head of the biceps femoris muscle. Ultimately, it branches into the deep and superficial peroneal nerves behind the proximal fibular head (14).

During the procedure, an RFA probe was used to precisely locate the target sensory nerve. This involved inserting the sterile 20G 150-mm RFA needle under fluoroscopic guidance to the suspected nerve location and applying a small electrical current to confirm targeting of the right common peroneal nerve, which was located more proximal, anterior, and medial than expected likely due to prior right knee arthroplasty (Fig. 1). The patient's symptoms were reproduced with sensory stimulation (15). This step was critical to ensure stimulation of the desired sensory peroneal nerve, while concurrently avoiding stimulation of the surrounding motor nerves.

Once the correct sensory nerve was identified, the PNS leads were implanted with a trajectory adapted to the patient's unique anatomical features and nerve transposition. PNS devices are typically implanted in a vertical trajectory to minimize the risk of kinks and

device damage. However, her significantly shortened femur posed an additional challenge. The decision was made to position the puncture site for the introducer approximately 2 inches above the intended target site. This strategic placement enabled a straight trajectory for the electrode array to the channel marker, which is imperative for the optimal functioning of the device. The introducer was then tunneled from the medial aspect of the thigh and advanced to the designated location, ultimately leading to the placement of the 4-contact electrode at the right common peroneal nerve (Fig. 2). A slight bend in the wiring, between the channel marker and receiver marker, was introduced, forming an upside-down "U" configuration. This allowed for comfortable and safe placement of the external transmitter.

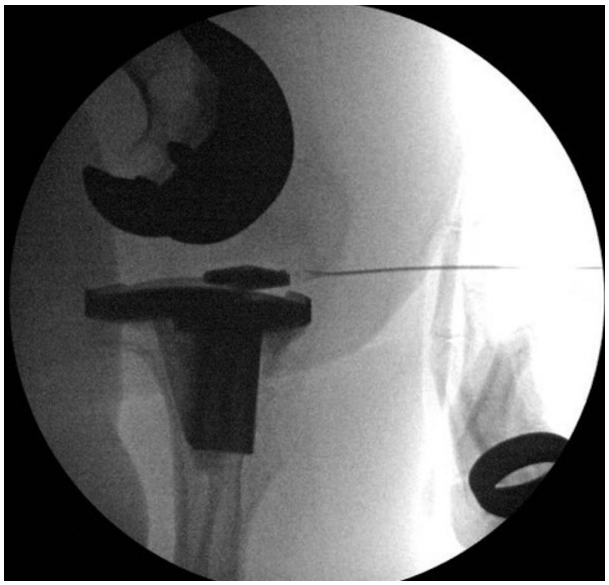

Fig. 1. RF cannula positioned at the right common peroneal nerve during sensory testing, which reproduced the patient's pain. RF, radiofrequency.

DISCUSSION

The application of the modified PNS implantation technique using RFA probe guidance in this case resulted in a significant improvement in pain management and patient outcomes. The precise identification of the sensory nerve, facilitated by the RFA probe, allowed for accurate placement of the PNS leads despite the complex anatomical challenges presented by the patient's achondroplasia. The RFA-guided approach ensured the leads were optimally positioned in close proximity to the common peroneal nerve, avoiding the stimulation of nearby motor fibers, which could have led to undesirable muscle contractions.

Following the procedure, the patient reported substantial pain relief, which was sustained over a 2-month follow-up period. The reduction in pain levels was accompanied by a marked decrease in opioid consumption, demonstrating the effectiveness of this targeted neuromodulation strategy. Additionally, no device-related complications were observed, further underscoring the safety and reliability of this approach.

PNS serves as an effective modality to treat chronic pain after conservative measures have failed. PNS for lower extremity neuropathy has shown promise in reducing patients' reliance on opioids and improving function at 6 months (16). Integrating PNS into the treatment plan earlier has been proposed to enhance patient outcomes by potentially reducing hospitalizations and clinic visits (17). A recent systematic review (18) describing the safety and effectiveness of PNS reported achieving at least 50% sustained pain relief in two-thirds of patients. Additionally, a case report (19) describing PNS for chronic postoperative pain after TKA targeted the patient's saphenous and superior lateral genicular nerves. The patient experienced significant pain reduction and function 2 months after lead removal and was able to discontinue all pain medications (19). PNS has shown favorable outcomes in pain management. However, innovative approaches may be required based on the patient's anatomy and past medical or surgical history.

Managing chronic pain in achondroplasia patients post-TKA is particularly challenging due to unique anatomical considerations. Achondroplasia patients typically exhibit shortened long bones, narrower spinal canals, and abnormal joint alignment, which can lead to altered nerve pathways and atypical locations of peripheral nerves (13). For example, the peroneal nerve may be positioned in a more atypical trajectory due to the altered anatomy of the knee joint and surrounding structures. This variability complicates the use of standard anatomical landmarks for PNS lead placement, as the nerve may not be located as expected based on conventional anatomy. Furthermore, the reduced anatomical space available for device implantation in patients with achondroplasia exacerbates these challenges. These anatomical variations significantly impair the reliability of conventional techniques, emphasizing the necessity of employing more precise methods, such as RFA-guided lead placement, to accurately target the

sensory peroneal nerve despite these anatomical differences. This case exemplifies the successful adaptation of PNS in a patient with particularly complex anatomy due to achondroplasia, highlighting the technique's versatility and potential for personalized pain management strategies.

RFA offers superior precision in targeting specific nerves compared to traditional PNS techniques. The RFA procedure utilizes a specialized needle equipped with an electrode, which is inserted near the target nerve under imaging guidance. Once the needle is correctly positioned, a small electric current is used to reproduce the patient's pain (19). This step is crucial as it confirms that the correct sensory nerve is being targeted, thereby avoiding the stimulation of motor nerves that can cause involuntary and painful muscle contractions.

Incorporating RFA techniques into PNS procedures enhances the accuracy of lead placement. Traditional PNS lead placement relies on anatomical landmarks and fluoroscopic guidance, where the leads are placed 0.5 cm to 3 cm away from the target nerve (4,8). This distance can reduce the effectiveness of the stimulation and increase the likelihood of stimulating nearby motor fibers. The RFA probe offers superior precision over the motor stimulation feature typically used in PNS placement, particularly in systems with external generators, where closer lead placement is crucial due to the higher electrical output required. This higher output broadens the stimulation field, which, although sufficient to achieve adequate nerve activation at distances up to 3 cm, also raises the risk of unintentionally stimulating nearby motor nerves. Such activation can cause discomfort and reduce the overall efficacy of the treatment. By allowing for exact targeting of sensory nerves, RFA minimizes these risks, ensuring that only the intended nerve is engaged. This precise approach is especially important in cases involving complex anatomy, where accurate lead placement is essential for optimizing therapeutic outcomes and minimizing adverse effects. There is limited existing research on the implementation of PNS in patients with anatomical challenges, such as achondroplasia.

CONCLUSIONS

The successful application of RFA-guided PNS in a patient with achondroplasia highlights the potential of this approach for broader clinical use. The precision provided by RFA in identifying and targeting sensory nerves can be beneficial for all patients undergoing PNS procedures, regardless of unique anatomical challenges. By ensuring that leads are placed in optimal proximity to the target nerve, this method can enhance the therapeutic outcomes of PNS, making it a more effective and reliable option for chronic pain management. Additionally, the use of RFA techniques in PNS procedures can reduce the likelihood of adverse effects, such as painful muscle contractions caused by inadvertent stimulation of motor nerves during the procedure. The positive outcomes observed in this case underscore the potential for this innovative approach to be considered for use in a broader patient population undergoing PNS procedures, particularly those with variable anatomical challenges.

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