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# *Spinal Cord Stimulation for Neuropathic Pain following a Spinal Cord Lesion with Past Spinal Surgical Histories Using a Paddle Lead Placed on the Rostral Side of the Lesion: Report of Three Cases*

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## Abstract

**Spinal cord parenchymal lesions may induce intractable neuropathic pain. However, the efficacy of conventional spinal cord stimulation for the neuropathic pain following spinal cord lesions remains to be controversial. In this study, we present three cases of spinal cord stimulation using a paddle lead at the rostral side of the spinal lesion causing pain symptoms. Good pain reductions were achieved using conventional stimulation in one case and using differential target multiplexed stimulation in two cases. Case 1: A 55-year-old man presented with neuropathic pain affecting his bilateral upper extremities due to a traumatic cervical spinal cord injury. Conventional stimulation via a paddle-type electrode was able to reduce the pain from 8 to 4 via a visual analog scale. Case 2: A 67-year-old man had undergone three spinal surgeries. He presented with pain and numbness of bilateral lower extremities due to a spinal cord lesion by thoracic disc herniation. Differential target multiplexed stimulation via a paddle-type electrode achieved excellent pain reduction, that is, from 9 to 2 on the visual analog scale. Case 3: An 80-year-old man presented with pain in his bilateral upper extremities due to a cervical spinal cord lesion caused by compression and spinal canal stenosis. Posterior cervical decompression and paddle-type electrode placement were performed simultaneously. Differential target multiplexed stimulation was able to achieve excellent pain reduction, from 7 to 2 on the visual analog scale. Spinal cord stimulation using a paddle lead at the rostral side of the spinal lesion and differential target multiplexed stimulation may provide significant opportunities for patients with intractable neuropathic pain following spinal cord lesions.**

Keywords: spinal cord stimulation, spinal cord injury, neuropathic pain, paddle, differential target multiplexed

## Introduction

A spinal cord parenchymal lesion is known to be caused by several pathogenetic mechanisms, such as trauma, tumor, vascular malformation, or severe spinal cord compression. Sensory fibers run through the dorsal spinal cord parenchyma, and damage on these sensory fibers may induce neuropathic pain. Spinal cord injury (SCI) may result in paralysis and other dysfunctions, typically pain symptoms. Post-SCI pain may exacerbate recovery of motor function, and it can further lead to depression or even suicide. Post-SCI pain can be divided into nociceptive and neuropathic categories. Post-SCI neuropathic pain is well known to be refractory to pharmacological therapies.[1)] Similarly, neuropathic pain following spinal cord lesions can result in similar conditions of post-SCI neuropathic pain. Therefore, pain control is one of the key focuses for patients with neuropathic pain following spinal cord le-

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sions. Various neurostimulation therapies, such as motor cortex stimulation, deep brain stimulation, or spinal cord stimulation (SCS), have been used to treat neuropathic pain following spinal cord lesions.[2] However, the efficacy of SCS for neuropathic pain following spinal cord lesions remains to be controversial because there have been no randomized controlled trials, and current treatment guidelines do not recommend it.[3,4] However, there have been reports of the use of conventional SCS for neuropathic pain following spinal cord lesions, and some have reported its efficacy.[5,6]

The optimal placements of SCS devices for neuropathic pain following spinal cord lesions are yet to be established. One of the mechanisms of the effect of SCS is based on gate control theory.[7,8] According to the theory, SCS alleviates pain by rostral side electric stimulation of the spinal lesion. Recently, new stimulation methods that are paresthesia-free have been developed. The new stimulation methods demonstrated more efficacy than conventional SCS.[9,10] Differential target multiplexed (DTM) stimulation, which is deemed superior to conventional stimulation, has been considered to be the latest new paresthesia-free SCS method.[11] The mechanisms of DTM stimulation are unique and specific, and they are distinct from other stimulation methods.[12]

In this study, we present three cases with good outcomes from SCS using a paddle lead for intractable neuropathic pain following spinal cord lesion. The paddle lead was placed on the rostral side of the previous spinal lesion by laminectomy under general anesthesia. Two of the three cases underwent the new DTM stimulation and achieved good pain reduction.

## Case Report

### Case 1

A 55-year-old man suffered from a head trauma 6 years earlier. He presented with tetraplegia without consciousness disturbance. Computed tomography (CT) showed dislocation of a cervical vertebral body (Fig. 1A). As per his magnetic resonance imaging (MRI) findings, compression of the spinal cord at the C6/7 level was detected (Fig. 1B). Cervical fusions were performed in the acute traumatic stage (Fig. 1C). However, MRI demonstrated residual high-intensity findings of the spinal cord (Fig. 1D). Motor function was noted to improve gradually, although pain at bilateral upper extremities remained (Fig. 1E). The pain was severe, and full-dose medical treatment had already been performed. Therefore, an SCS trial was planned using percutaneous cylinder-type electrodes (Model 977A190; Medtronic Inc., Minneapolis, MN, USA). Adhesion was so strong that the cylinder-type electrodes were placed on the caudal side of the SCI (Fig. 1F). The SCS trial was deemed not effective, although the patient demanded another method to alleviate the pain because as it was severe. Then, a paddle-type electrode (Model 977C190; Medtronic Inc.) was placed at the rostral side of the previous surgical site by laminectomy under general anesthesia (Fig. 1G, H). At the same time, an implantable pulse generator (IPG) was implanted (Intellis; Medtronic Inc.). Tonic stimulation (frequency 5 Hz, pulse width 500 μs) achieved pain reduction from 8 to 4 on a visual analog scale (VAS), although high-dose stimulation was found ineffective. At that time, DTM stimulation was not available. The effects of SCS have continued for 3 years, and oral medications including pregabalin and antidepressant and non-steroidal anti-inflammatory drugs were decreased.

### Case 2

A 67-year-old man presented initially 8 years earlier with low back pain and numbness of the left lower extremity. He had undergone three spinal surgeries. The first surgery was Th10/11 anterior lateral fusion 8 years earlier, and the second surgery was L5/S1 fusion 6 years earlier, and these fusions were confirmed on CT (Fig. 2A). However, his MRI showed compression of the spinal cord by thoracic disc herniation with high-intensity findings at the Th10/11 level (Fig. 2B). The third surgery, that is, thoracic posterior decompression, was performed 5 years earlier. Laminectomies of Th10 and 11 were confirmed on CT (Fig. 2C). MRI showed residual high-intensity findings of the spinal cord (Fig. 2D). After the third surgery, pain and numbness of the bilateral lower extremities and a gait disturbance were noted to appear (Fig. 2E). The patient continued to suffer from severe pain despite three spinal surgeries and sufficient medical treatment. Strong epidural adhesion was expected due to the history of multiple spinal surgeries. Therefore, a paddle-type electrode (Model 977C165; Medtronic Inc.) was placed at the rostral side of the previous surgical site via laminectomy (Fig. 2F, G). At the same surgery, an IPG was implanted. DTM stimulation achieved excellent pain reduction, from 9 to 2 on the VAS. Furthermore, the numbness of bilateral lower extremities was relieved nearly by half, and his gait disturbance also improved. These effects continued for 1 year.

### Case 3

An 80-year-old man presented with numbness of the extremities about 30 years earlier. He underwent cervical surgery and anterior fusion, but the numbness of the extremities did not improved. Unfortunately, he presented with new-onset pain in his bilateral upper extremities and deteriorated gradually (Fig. 3A). The patient had undergone conservative management and had severe pain for a long time. MRI and CT showed C4/5 and C6/7 level spinal cord compression with high-intensity findings and spinal canal stenosis (Fig. 3B-E). Combination surgery of posterior decompression and paddle-type electrode placement was performed, using the following surgical procedures. The vertebral arches from C3 to C6 were opened in double-

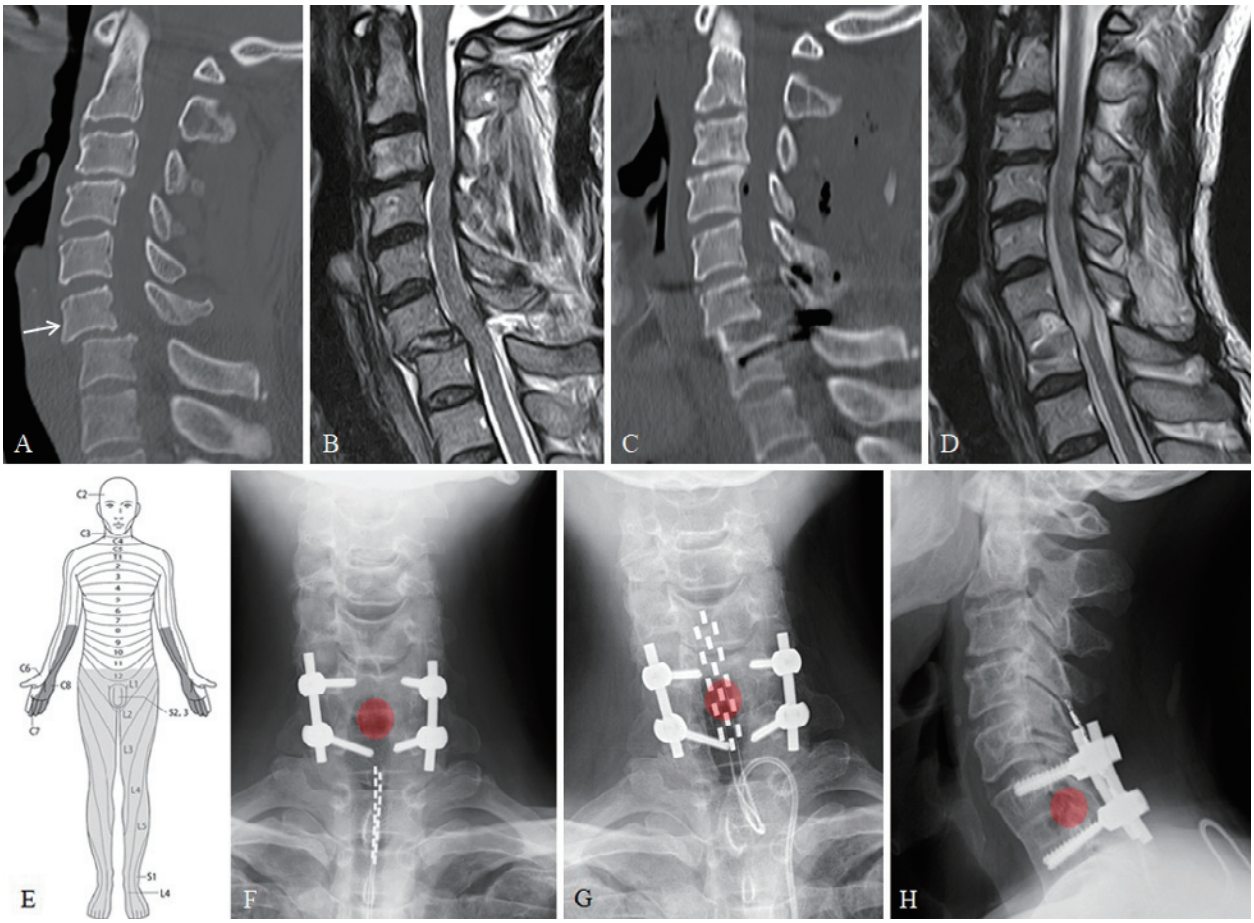


**Fig. 1**
**A, B: Cervical images of the acute phase of head trauma. A: Computed tomography shows anterior dislocation of a cervical vertebral body (arrow: C6 vertebral body). B: Magnetic resonance T2-weighted image shows compression of the spinal cord at the C6/7 level.**
**C, D: Cervical images of the chronic phase after cervical fusion surgery. C: Reset and fusion of the cervical vertebral body are confirmed via computed tomography. D: Magnetic resonance T2-weighted image demonstrates residual high-intensity findings of the spinal cord at the C6/7 level.**
**E: Schematic diagram shows the location of sensory disturbances (dark gray: pain, light gray: numbness).**
**F-G: Cervical X-rays show the location of spinal cord stimulation devices (red circle: location of spinal cord injury). F: Cylinder-type electrodes placed at the caudal side of the spinal cord injury. G, H: A paddle-type electrode placed at the rostral side of the spinal cord injury.**

door form, the superior margin of the C7 vertebral arch was whittled, the yellow ligament was removed, a paddle-type electrode was placed (Model 977C265; Medtronic Inc.), laminoplasties were performed, and an IPG was implanted (Fig. 3F, G). The X-ray showed the paddle-type electrode located at the rostral side of the C6/7 level (Fig. 3H, I). After the decompression, the pain in his bilateral upper extremities persisted without SCS 2 days from the surgery. Then, DTM stimulation was started and achieved excellent pain reduction from 7 to 2 on the VAS, and the effect continued for 1 year.

## Discussion

It has been estimated that 30 to 80% of SCI patients experience chronic pain, and nearly one-third of SCI patients suffer from severe pain.[13,14] Based on the location of pain from the level of the neurological injury, neuropathic pain can be categorized into above-level, at-level, and below-level pain.[15] More than 30% of patients were found to have developed below-level pain within 5 years after injury.[16] One of the mechanisms of the below-level SCI pain involves dysfunction of the spinothalamic tract.[17,18] The damaged spinothalamic tracts following SCI are often related to enhanced neuronal excitability and reduced descending pain inhibition, leading, in turn, to chronic central neuro-

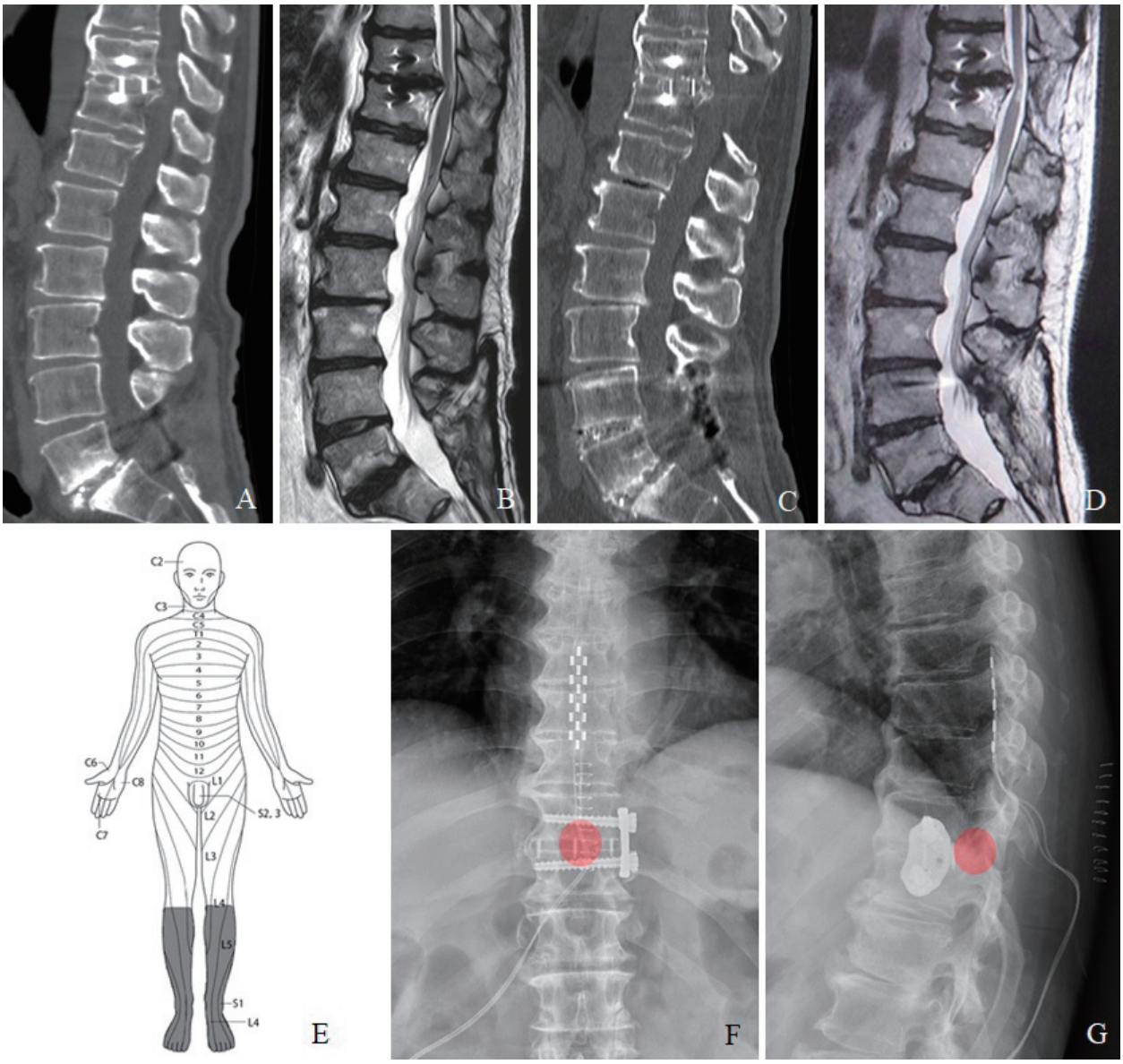


**Fig. 2**
**A, B: Lumbar images after the second spinal surgery. A: Computed tomography shows Th10/11 and L5/S1 fusions. B: Magnetic resonance T2-weighted image shows compression of the spinal cord by thoracic disc herniation with high-intensity findings at the Th10/11 level.**
**C, D: Lumbar images after the third spinal surgery. C: Thoracic posterior decompression is confirmed on computed tomography. D: Magnetic resonance T2-weighted image demonstrates residual high-intensity findings of the spinal cord at the Th10/11 level.**
**E: Schematic diagram shows the location of sensory disturbances (dark gray: pain).**
**F, G: Thoracic X-rays show a paddle-type electrode placed at the rostral side of the spinal cord injury (red circle: location of spinal cord injury).**

pathic pain.[19] On a cellular level, microglial cells and astrocytes are activated in the early phase after SCI to remove debris and damaged cells.[20] Then, these glial cells can be persistently activated to release several chemicals, including glutamate, pro-inflammatory cytokines, and reactive oxygen species. These chemicals are known to contribute to the development of central sensitization and neuropathic pain. In addition, hypersensitive neurons in the dorsal column of the spinal cord mediate pain secondary to increased aberrant background activity and altered sodium channel currents. Non-traumatic spinal cord parenchymal lesions are often induced by severe spinal cord compression or spinal lesions such as tumors or vascular malformations. These cases also have histories of spinal surgery of decompression or lesion removal. In cases of residual damage of spinal cord parenchyma, the lesion may induce

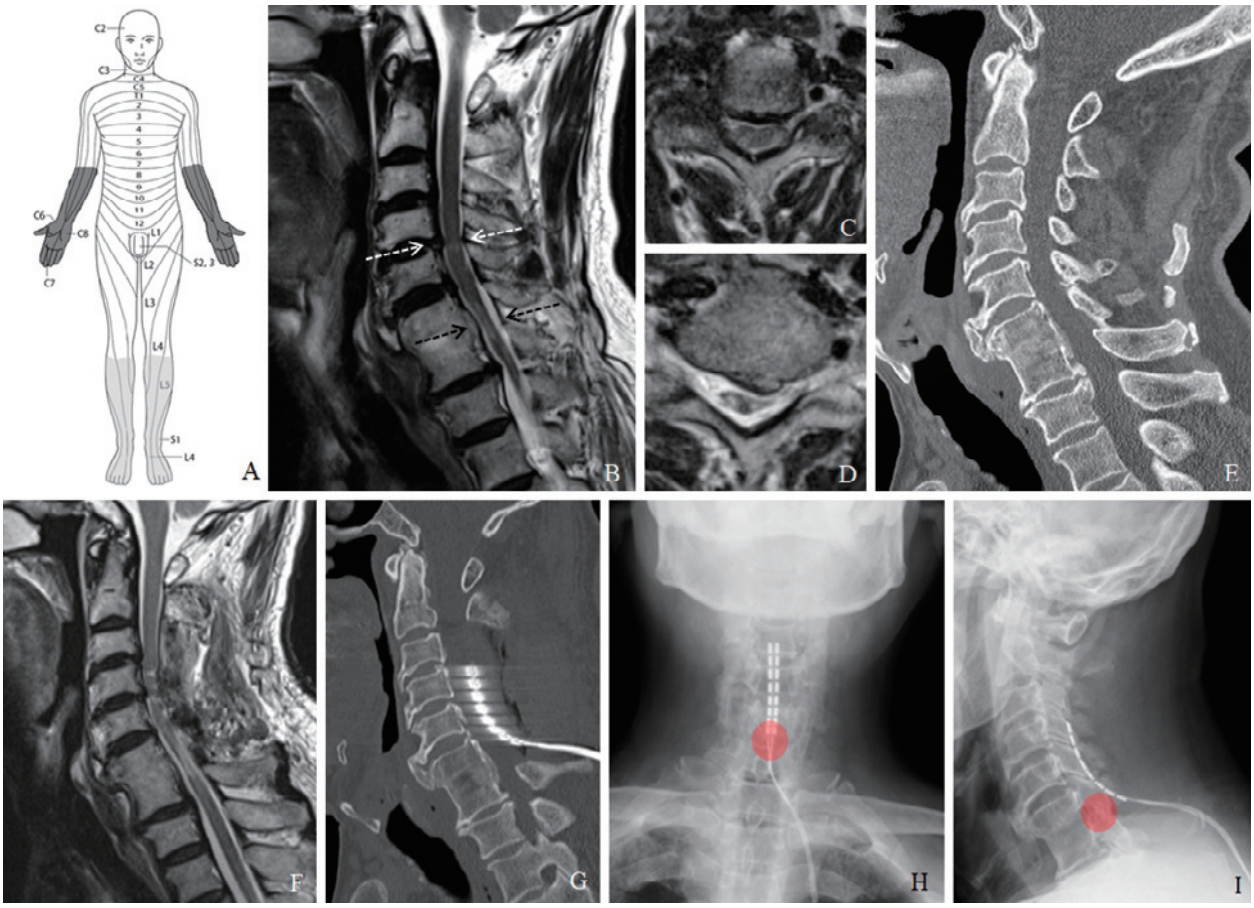


**Fig. 3**
**A: Schematic diagram shows the location of sensory disturbances (dark gray: pain, light gray: numbness).**
**B-E: Cervical images before implantation of the spinal cord stimulation device.**
**B-D: Magnetic resonance T2-weighted images show C4/5 and C6/7 level spinal cord compression with high-intensity findings (C, white arrows: C4/5, D, block arrows: C6/7). E: Computed tomography shows the previous fusion of C6/7 and spinal canal stenosis.**
**F, G: Cervical images show cervical posterior decompression and placement of a spinal cord stimulation device (F: magnetic resonance image, I: computed tomography).**
**H, I: The X-rays show a paddle-type electrode located at the rostral side of the C6/7 level (red circle: location of spinal cord injury).**

neuropathic pain, which is similar to the pathogenesis of post-SCI pain.

Conventional SCS is known to deliver mild electrical pulses and elicit comfortable paresthesia.[21] In conventional SCS, stimulation parameters including frequency, pulse width, and voltage are modified.[22] It is deemed essential that the elicited paresthesia overlaps the painful area in order to ameliorate the pain symptoms.[22] The mechanisms of the analgesic effect of conventional SCS are activation of spinal GABAergic interneurons in the dorsal horn and of descending pain inhibitory pathways.[7,8,23] Therefore, conventional SCS for alleviating pain symptoms requires intact dorsal column structures and afferent pathways from the peripheral nervous system to the central nervous system.[7] A review of 27 clinical studies reported a success rate of 30-40% for conventional SCS treatment for neuropathic pain following spinal cord lesions.[24] In general, patients with neuropathic pain following spinal cord lesions are much less responsive to conventional SCS than those with failed back surgery pain syndromes or peripheral neuropathic pain. In a larger cohort study, conventional SCS was found to be more effective in reducing pain in patients with incomplete spinal cord lesions compared with complete lesions.[25] The efficacy of conventional SCS for neuropathic pain following spinal cord lesions depends on the number of residual fibers and neuronal structures within the injured cord.[21,26]

DTM stimulation has been shown to modulate gene expressions in the spinal cord at the site of stimulation and at the dorsal root ganglion.[12] The DTM approach uses multiple electrical signals to modulate glial cells and neurons and rebalance their interactions.[12] Fishmann et al. reported the superiority of DTM stimulation, as compared to conventional SCS for chronic low back pain.[11] In total, 126

patients were randomized across 12 centers, and 94 patients received permanent SCS implantation. The chronic low back pain responder rate was 80.1% with DTM stimulation, which was superior to 51.2% with conventional SCS. These results were sustained for 12 months. There are few reports of the use of DTM stimulation for post-SCI neuropathic pain. In the present cases 2 and 3, DTM stimulation achieved excellent pain reduction that continued. Activity and modulation of glial cells are determined to be key factors in both post-SCI neuropathic pain and DTM stimulation.[12,20]

SCS is a not radical, but is a supportive treatment for intractable pain. In addition, implantation of SCS devices has posed the risk of device-related problems. Therefore, it is essential to rule out curable spinal or peripheral nerve disorders inducing intractable pain before SCS procedures. The indication for SCS is intractable neuropathic pain without curable disorders, and not achieving sufficient alleviation despite sufficient medical treatment. In these present cases, curable disorders were ruled out by spinal surgery specialists. SCS is generally performed by two staged procedures. Initially, the alleviating effects of SCS are assessed by an SCS trial using cylinder-type electrodes via percutaneous insertion under local anesthesia. If apparent alleviating effects are confirmed, IPG implantation is then performed next. Atypical SCS procedures were used in these present cases. Therefore, the procedures should only be applied for intractable neuropathic pain following a spinal cord lesion with a history of spinal surgery.

Patients presenting with neuropathic pain following spinal cord lesions often have past histories of spinal surgery. Insertion of an electrode via a percutaneous approach from caudal of the previous surgical side may pose several risks. First, passing the electrode around the previous surgical site may be a challenge due to epidural adhesions. Second, passing the previous surgical site may impair normal structures, including the dura mater or the spinal cord. Finally, passing the previous surgical site may induce bleeding from neovascular vessels of granulation tissues. According to the gate control theory,[7,8] the SCS electrode device should be placed on the rostral side of the lesion that causes the pain symptoms. However, the SCS electrode device may be more likely to be placed on the caudal side of the lesion in patients with neuropathic pain following spinal cord lesions. In the present case 1, conventional SCS on the rostral side of the lesion was able to achieve good pain reduction, although the same SCS on the caudal side of the lesion was not effective. The method of placing the electrode device using laminectomy has two advantages. One is that the device is certainly placed on the rostral side of the previous surgery. The other is that the paddle-type electrode device is safely inserted. The paddle-type electrode delivers energy more efficiently with lower rates of migration. However, its disadvantage is the need to perform laminectomy under general anesthesia. In the present case 3, spinal decompression and placement of the electrode were performed on the same surgery. Therefore, there are limitations of the assessments of the alleviating effects of SCS. SCS was not started for 2 days to detect early symptoms of postoperative complications. The fact that the pain persisted without SCS, but excellent pain reduction was achieved after starting DTM stimulation, indicates the alleviating effects of SCS.

SCS using a paddle lead at the rostral side of the spinal lesion may provide significant opportunities for patients with intractable neuropathic pain following spinal cord lesions. Furthermore, DTM stimulation may be one of the effective new paresthesia-free stimulation methods for intractable neuropathic pain following spinal cord lesions.

## Abbreviation

CT: computed tomography
DTM: differential target multiplexed
IPG: implantable pulse generator
MRI: magnetic resonance image
SCI: spinal cord injury
SCS: spinal cord stimulation
VAS: visual analog scale

## Informed Consent

Informed consent for publication was obtained from all patients.

## Conflicts of Interest Disclosure

The authors have no conflicts of interest directly relevant to the content of this article.

## References

1) Mehta S, McIntyre A, Janzen S, Loh E, Teasell R: Systematic review of pharmacologic treatments of pain after spinal cord injury: an update. *Arch Phys Med Rehabil* 97: 1381-1391, 2016
2) Dworkin RH, O'Connor AB, Kent J, et al.: Interventional management of neuropathic pain: NeuPSIG recommendations. *Pain* 154: 2249-2261, 2013
3) Cruccu G, Garcia-Larrea L, Hansson P, et al.: EAN guidelines on central neurostimulation therapy in chronic pain conditions. *Eur J Neurol* 23: 1489-1499, 2016
4) Mehta S, Guy SD, Bryce TN, et al.: The CanPain SCI clinical practice guidelines for rehabilitation management of neuropathic pain after spinal cord: screening and diagnosis recommendations. *Spinal Cord* 54: S7-S13, 2016
5) Dombovy-Johnson ML, Hunt CL, Morrow MM, Lamer TJ, Pittelkow TP: Current evidence lacking to guide clinical practice for spinal cord stimulation in the treatment of neuropathic pain in spinal cord injury: a review of the literature and a proposal for future study. *Pain Pract* 20: 325-335, 2020
6) Huang Q, Duan W, Sivanesan E, et al.: Spinal cord stimulation for pain treatment after spinal cord injury. *Neurosci Bull* 35: 527-

539, 2019
7) Costigan M, Woolf CJ: No DREAM, No pain. Closing the spinal gate. *Cell* 108: 297-300, 2002
8) Melzack R, Wall PD: Pain mechanisms: a new theory. *Science* 150: 971-979, 1965
9) Hou S, Kemp K, Grabois M: A systematic evaluation of burst spinal cord stimulation for chronic back and limb pain. *Neuromodulation* 19: 398-405, 2016
10) Kapural L, Yu C, Doust MW, Gliner BE: Novel 10-kHz high-frequency therapy (HF10 therapy) is superior to traditional low-frequency spinal cord stimulation for the treatment of chronic back and leg pain: the SENZA-RCT randomized controlled trial. *Anesthesiology* 123: 851-860, 2015
11) Fishman M, Cordner H, Justiz R, et al.: Twelve-month results from multicenter, open-label, randomized controlled clinical trial comparing differential target multiplexed spinal cord stimulation and traditional spinal cord stimulation in subjects with chronic intractable back pain and leg pain. *Pain Pract* 21: 912-923, 2021
12) Smith WJ, Cedeño DL, Thomas SM, Kelley CA, Vetri F, Vallejo R: Modulation of microglial activation states by spinal cord stimulation in an animal model of neuropathic pain: comparing high rate, low rate, and differential target multiplexed programming. *Mol Pain* 17: 1-9, 2021
13) Margot-Duclot A, Tournebise H, Ventura M, Fattal C: What are the risk factors of occurrence and chronicity of neuropathic pain in spinal cord injury patients? *Ann Phys Rehabil Med* 52: 111-123, 2009
14) Widerström-Noga E, Biering-Sørensen F, Bryce TN: The international spinal cord injury pain basic data set (version 2.0). *Spinal Cord* 52: 282-286, 2014
15) Widerström-Noga E, Biering-Sørensen F, Bryce TN, et al.: the international spinal cord injury pain extended data set (Version 1.0). *Spinal Cord* 54: 1036-1046, 2016
16) Siddall PJ, McClelland JM, Rutkowski SB, Cousins MJ: A longitudinal study of the prevalence and characteristics of pain in the first 5 years following spinal cord injury. *Pain* 103: 249-257, 2003
17) Finnerup NB, Johannesen IL, Fuglsang-Frederiksen A, Bach FW, Jensen TS: Sensory function in spinal cord injury patients with and without central pain. *Brain* 126: 57-70, 2003
18) Zeilig G, Enosh S, Rubin-Asher D, Lehr B, Defrin R: The nature and course of sensory changes following spinal cord injury: predictive properties and implications on the mechanism of central pain. *Brain* 135: 418-430, 2012
19) Gruener H, Zeilig G, Laufer Y, Blumen N, Defrin R: Differential pain modulation properties in central neuropathic pain after spinal cord injury. *Pain* 157: 1415-1424, 2016
20) D'Angelo R, Morreale A, Donadio V, et al.: Neuropathic pain following spinal cord injury: what we know about mechanisms, assessment and management. *Eur Rev Med Pharmacol Sci* 17: 3257-3161, 2013
21) Linderoth B, Foreman RD: Conventional and novel spinal stimulation algorithms: hypothetical mechanisms of action and comments on outcomes. *Neuromodulation* 20: 525-533, 2017
22) Heijmans L, Joosten EA: Mechanisms and mode of action of spinal cord stimulation in chronic neuropathic pain. *Postgrad Med* 132: 17-21, 2020
23) Shimoji K, Shimizu H, Maruyama Y, Matsuki M, Kuribayashi H, Fujioka H: Dorsal column stimulation in man: facilitation of primary afferent depolarization. *Anesth Analg* 61: 410-413, 1982
24) Lagauche D, Facione J, Albert T, Fattal C: The chronic neuropathic pain of spinal cord injury: which efficiency of neuropathic stimulation? *Ann Phys Rehabil Med* 52: 180-187, 2009
25) Tasker RR, DeCarvalho GT, Dolan EJ: Intractable pain of spinal cord origin: clinical features and implications for surgery. *J Neurosurg* 77: 373-378, 1992
26) Barchini J, Tchachaghian S, Shamaa F, et al.: Spinal segmental and supraspinal mechanisms underlying the pain-relieving effects of spinal cord stimulation: an experimental study in a rat model of neuropathy. *Neuroscience* 215: 196-208, 2012

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