Case Reports

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Successful application of burst spinal cord stimulation for refractory upper limb pain: a case series

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Abstract

Spinal cord stimulation (SCS) has been used to treat sustained pain that is intractable despite various types of treatment. However, conventional tonic waveform SCS has not shown promising outcomes for spinal cord injury (SCI) or postamputation pain. The pain signal mechanisms of burst waveforms are different to those of conventional tonic waveforms, but few reports have presented the therapeutic potential of burst waveforms for the abovementioned indications. This current case report describes two patients with refractory upper limb pain after SCI and upper limb amputation that were treated with burst waveform SCS. While the patients could not obtain sufficient therapeutic effect with conventional tonic waveforms, the burst waveforms provided better pain reduction with less discomfort. However, further studies are necessary to better clarify the mechanisms and efficacy of burst waveform SCS in patients with intractable pain.

Keywords

Amputation, intractable pain, spinal cord injury, spinal cord stimulation

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Introduction

In the past decades, there have been significant advances in the discovery of pain signal mechanisms and treatments for pain relief.[1,2] However, despite these medical advances, chronic pain is still difficult to

manage.[3] Spinal cord injury or postamputation pain is often persistent and intractable despite various types of treatment.[4–6] Spinal cord stimulation (SCS) has been used for decades to alleviate pain in patients that are not responsive to treatment.[7] However, the results for SCS for pain management have been disappointing compared with those for other indications such as peripheral neuropathy, failed back surgery syndrome, complex regional pain syndrome and multiple sclerosis.[8–12]

Burst waveform SCS was developed as an alternative to conventional tonic waveform SCS.[13] Compared with the constant, unchanging pulses that are delivered during conventional tonic waveform SCS, five pulses are delivered at 500 Hz and the burst repeats at 40 Hz in burst SCS.[14] Waveforms are similar in pattern to the neuron firing that occurs naturally in the central nervous system. The pain signal mechanisms of burst waveforms are different from those of conventional tonic waveforms.[15,16] Burst waveforms may better stimulate both the medial and lateral pain pathways of the spinothalamic tract and are anticipated to have a better outcome than conventional waveforms.

However, to the best of our knowledge, few reports have presented the therapeutic potential of burst waveforms for refractory upper limb pain not responding to conventional tonic waveforms.[17] This current case report describes the use of burst waveform SCS in patients with refractory upper limb pain after spinal cord injury and upper limb amputation.

Case report

Case 1

In March 2019, a 59-year-old male patient with severe pain in both upper extremities secondary to a suspected spinal cord injury subsequent to a cervical interbody fusion surgery at C4–C5 was referred to the pain clinic at Korea University Anam Hospital, Seoul, Republic of Korea. He complained of sharp, tingling and scratching pain over 9 years; the mean score on a numerical rating scale (NRS; 0 = no pain; and 10 = worst imaginable pain) was 7. He also complained of paroxysmal pain similar to an electric shock (NRS 10) lasting approximately 5 min, more than 20 times a day. Magnetic resonance imaging (MRI) revealed cervical myelomalacia at the spinal cord between the C4 and C5 levels. The narrowest region of the anteroposterior diameter of the cervical canal was 6.95 mm at the C4/C5 level, which was anticipated to cause difficulty in inserting the lead (Figure 1). He had tried several combinations of medications, including anticonvulsants, antidepressants, anti-inflammatory drugs, muscle relaxants and opioids, but none were effective. Before presenting to our hospital, he underwent several procedures, such as nerve blocks, radiofrequency rhizotomy and sympathectomy, but none were effective. As he had experienced severe, intractable pain for over 9 years, had depression/psychologic impairments and sensory issues, and was unresponsive to peripheral treatments, it was decided to try a trial of SCS.

As a consequence of his prior history of surgery and procedures on the cervical spine and the MRI findings, severe adhesions in the posterior epidural space were expected. Therefore, the procedure was performed under general anaesthesia. A single eight-contact lead (Prodigy MRI™; Abbott Korea Ltd., Seoul, South Korea) was placed at the distal contact at the C3 vertebral body and the leads were positioned slightly to the left of the anatomical midline. A second lead could not be placed due to adhesions in the epidural space (Figure 2).

The patient underwent a trial of multiple stimuli and intensities over a 2-week period.

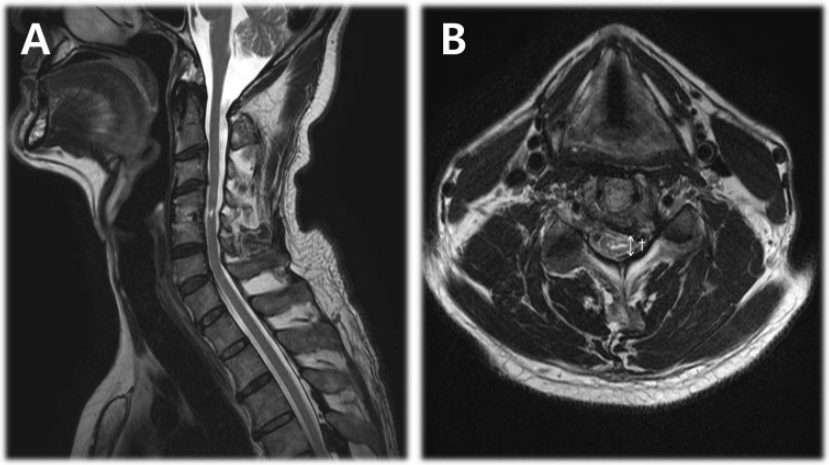

Figure 1. Sagittal (A) and axial (B) magnetic resonance images of a 59-year-old male patient (case 1) that presented with severe pain in both upper extremities secondary to a suspected spinal cord injury subsequent to a cervical interbody fusion surgery at C4–C5. He complained of sharp, tingling and scratching pain over 9 years and paroxysmal pain similar to an electric shock lasting approximately 5 min, more than 20 times a day. Myelomalacia was observed between the C4 and C5 levels. †The narrowest region of the anteroposterior diameter of the cervical canal was 6.95 mm at the C4/C5 level, which was anticipated to cause difficulty in inserting the lead.

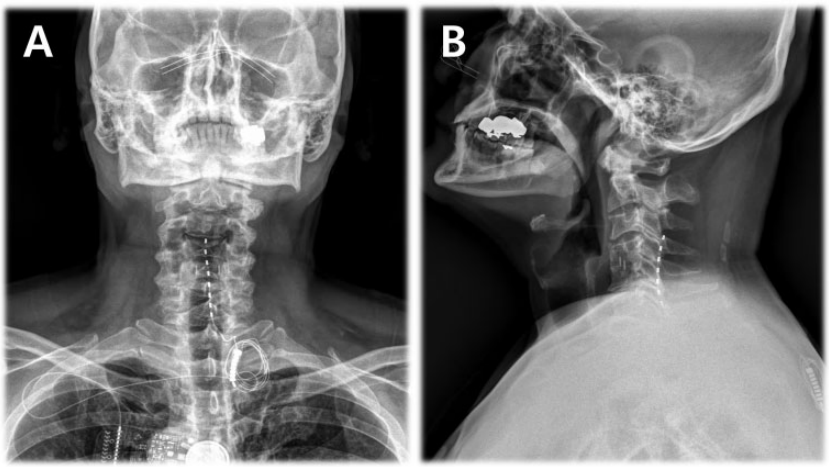

Figure 2. Anteroposterior view (A) and lateral view (B) plain X-rays taken after trial lead placement in a 59-year-old male patient (case 1) that presented with severe pain in both upper extremities secondary to a suspected spinal cord injury subsequent to a cervical interbody fusion surgery at C4–C5. He complained of sharp, tingling and scratching pain over 9 years and paroxysmal pain similar to an electric shock lasting approximately 5 min, more than 20 times a day. A single eight-contact lead was placed at the distal contact at the C3 vertebral body and the leads were positioned slightly to the left of the anatomical midline. A second lead could not be placed due to adhesion in the epidural space.

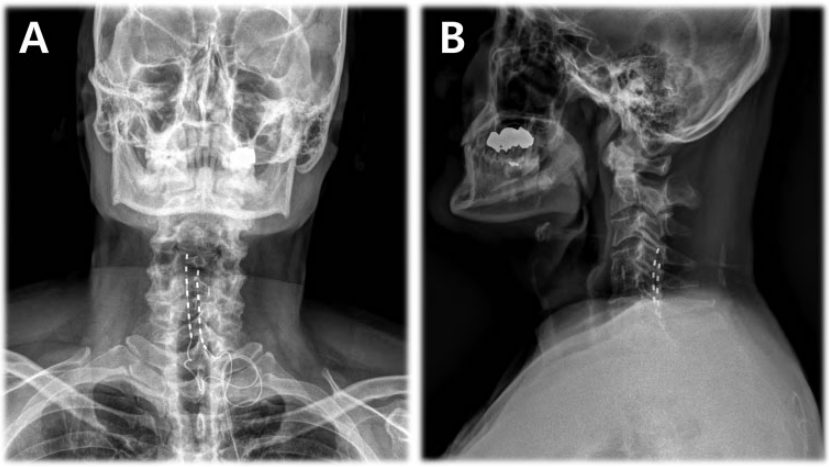

Figure 3. Anteroposterior view (A) and lateral view (B) plain X-rays taken after permanent lead implantation in a 59-year-old male patient (case 1) that presented with severe pain in both upper extremities secondary to a suspected spinal cord injury subsequent to a cervical interbody fusion surgery at C4–C5. He complained of sharp, tingling and scratching pain over 9 years and paroxysmal pain similar to an electric shock lasting approximately 5 min, more than 20 times a day. The procedure successfully advanced another lead at the right side at the C4–C7 levels.

When tonic waveforms were applied (pulse width 300 ms, frequency 30 Hz, amplitude 1.0 mA), although the pain intensity decreased to NRS 4–5, an uncomfortable tingling sensation was reported when the amplitude increased to >1.0 mA. However, when burst waveforms were applied (five pulses per burst, intraburst frequency 500 Hz, pulse width 1000 ms, frequency 40 Hz, amplitude 0.2 mA), the mean pain score decreased to NRS 2–3 and the frequency and intensity of the severe paroxysmal pain decreased to 2–3 times a day and NRS 4–5, respectively. Tingling sensations were not experienced even when the amplitude was increased to 0.35 mA. However, the pain decreased only in the left upper extremity.

After the trial, implantation was performed. The procedure successfully advanced another lead at the right side at the C4–C7 levels (Figure 3). The battery was placed at the right buttock of the patient without any complications. After implantation, the pain in both upper extremities decreased to NRS 2–3. The episodes of severe paroxysmal pain decreased to 2–3 times a day and the intensity was reduced to NRS 3–4. At 1-month follow-up, the intensity of continuous and paroxysmal pain slightly increased to NRS 3–4 and 4–5, respectively. The frequency of paroxysmal pain decreased to 2–3 times a day and showed no change until the 6-month follow-up. At follow-up, the patient's complaint about depression and other psychological symptoms also showed improvement. Moreover, the patient did not complain of other adverse effects such as pain at the implantation site. However, despite the progress of symptoms, the patient maintained the previous opioid dose due to the residual pain and the possibility of opioid dependency.

Case 2

In September 2019, a 63-year-old male patient with chronic pain in the right hand

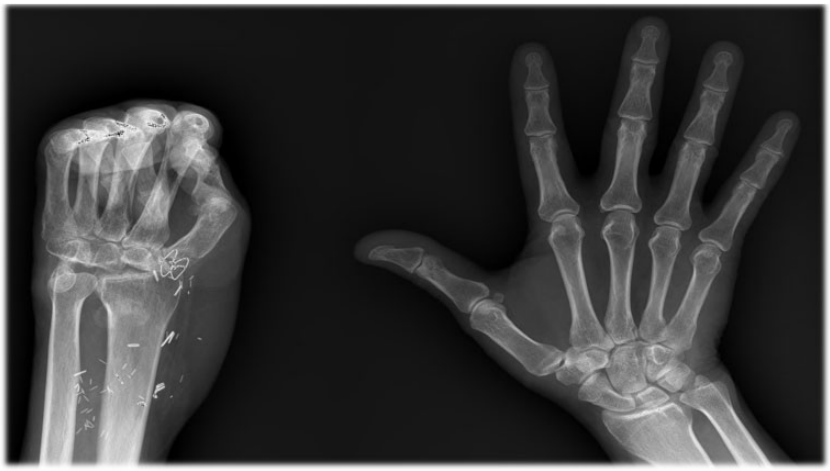

Figure 4. Plain X-ray of the hands of a 63-year-old male patient (case 2) with chronic pain in the right hand. He had undergone right hand amputation at the wrist due to an industrial accident 5 years previously and complained of phantom limb pain in the distribution of his former second and third digits and the volar aspect of the previous palm and pain at the stump despite reconstruction surgery.

was referred to the pain clinic at Korea University Anam Hospital, Seoul, Republic of Korea. He had undergone right hand amputation at the wrist due to an industrial accident 5 years previously and complained of phantom limb pain in the distribution of his former second and third digits and the volar aspect of the previous palm and pain at the stump despite reconstruction surgery to the maximum extent possible (Figure 4). The dull, throbbing pain was rated 9–10 on the NRS and aggravated with mechanical touch and temperature changes. He was treated with several combinations of medications, including anticonvulsants, antidepressants, anti-inflammatory drugs, muscle relaxants and opioids, but none were effective. Further, he had undergone several interventional procedures, including thoracic sympathetic ganglion block/neurolysis and single/continuous brachial plexus block, but none were effective. Because he had sustained severe, intractable pain with depression/psychological impairment and was unresponsive to peripheral treatment, a trail of SCS was planned. An eight-contact lead (Prodigy MRI^{TM}; Abbott Korea Ltd.) was placed percutaneously slightly left from the middle posterior epidural space at the C5–C7 levels under local anaesthesia (Figure 5). He underwent a trial of multiple stimuli and intensities over a 3-week period. Both tonic and burst waveforms were tested. During tonic waveforms (pulse width 300 ms, frequency 30 Hz, amplitude 1.2–1.3 mA), the pain intensity reduced to NRS 4. However, because he complained of an intolerable tingling sensation, burst waveforms were used (five pulses per burst, intraburst frequency 500 Hz, pulse width 1000 ms, frequency 40 Hz, amplitude 0.15 mA). Subsequently, the pain intensity reduced to NRS 2–3 and he did not complain of other adverse effects. Therefore, permanent lead implantation was performed. The pain intensity was maintained at NRS 2–3 at the 9-month follow-up. In this case, it was possible to discontinue the previously used opioid. At follow up, the patient's complaint about depression and other psychological symptoms showed

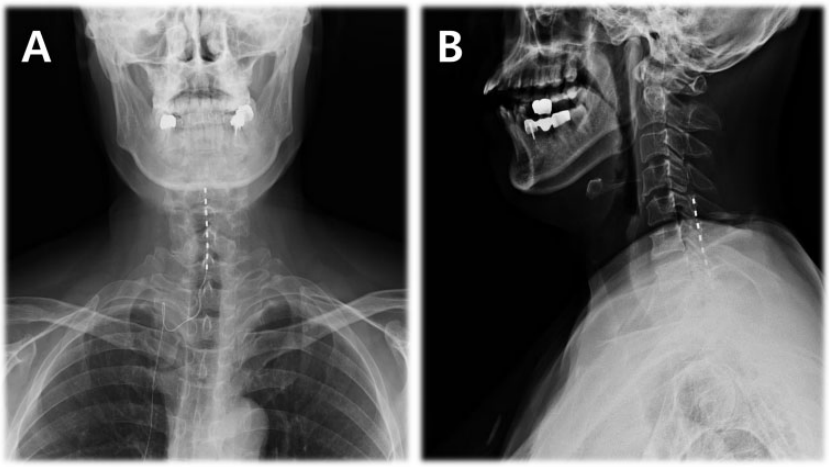

Figure 5. Anteroposterior view (A) and lateral view (B) plain X-rays taken after trial lead implantation in a 63-year-old male patient (case 2) with chronic pain in the right hand. He had undergone right hand amputation at the wrist due to an industrial accident 5 years previously and complained of phantom limb pain in the distribution of his former second and third digits and the volar aspect of the previous palm and pain at the stump despite reconstruction surgery. An eight-contact lead was placed percutaneously slightly left from the middle posterior epidural space at the C5–C7 levels under local anaesthesia.

improvement, and he did not complain of other adverse effects such as pain at the implantation site.

The Institutional Review Board of Korea University Anam Hospital, Seoul, Republic of Korea waived the authorization requirements for these two case reports. These two patients gave their written informed consent to publish their clinical data in medical journals. This study followed the CARE checklist.[18] Details of both patients' clinical information are summarized in Table 1.

Discussion

This current case report describes successful outcomes in two patients with refractory upper limb pain after spinal cord injury and upper limb amputation using burst waveform SCS. Although conventional tonic waveform SCS is an effective treatment for sustained intractable painful diseases, such as peripheral neuropathies, failed back surgery syndrome, complex regional pain syndrome and multiple sclerosis,[19] no promising outcomes for spinal cord injury or postamputation pain have been reported.[8–12] In a previous study,[20] conventional tonic waveform SCS failed in 80% patients with amputation-related pain and 65% patients with cord neuropathy. Hence, the application of SCS for spinal cord injury or postamputation pain cannot not be strongly recommended according to the guidelines regarding SCS application for different indications.[21,22]

In these two current cases, conventional tonic waveform SCS was initially applied to treat refractory upper limb pain. However, it was not very effective for pain reduction in either patient. One reason for this ineffectiveness might be related to the centralization of pain. Both patients had pain for a long period of time and showed features of centralized pain, such as spreading of pain, emotional deterioration and a general decline in their condition before the procedure.[23,24] This centralization seems to be

Table 1. Summary of spinal cord stimulation (SCS) profiles and pain scores for two patients with refractory upper limb pain after spinal cord injury and upper limb amputation that were treated with burst SCS application.

	Case 1	Case 2
Lead placement	C4–C7	C5–C7
Burst waveform programme parameters		
Pulses per burst, *n*	5	5
Intraburst frequency, Hz	500	500
Pulse width, ms	1000	1000
Frequency, Hz	40	40
Amplitude, mA	0.2	0.15
NRS pain scores		
Baseline	7	9–10
After procedure	2–3	2–3
Follow-up (>6 months)	3–5	2–3

NRS, numerical rating scale.

closely related to the emotional aspects of pain in the medial pathway of the corticospinal tract.[25]

In these two current cases, when the burst waveform mode was applied, the pain intensity decreased by more than 50%. This may be because the characteristics and pain signal mechanisms of burst waveforms are different to those of tonic waveforms. Both tonic and burst modes effectively deliver waveforms to the lateral and descending pathways, but the medial pathway is better stimulated by burst waveforms.[16,26] In addition, burst waveforms more effectively activate the cerebral cortex than tonic waveforms,[16,27] which might also support the outcomes in these current two cases.

In these two current cases, both patients reported paresthesia in the region of stimulation with conventional tonic waveforms, which prevented them from maintaining the mode. However, both patients did not report paresthesia in the region of stimulation with burst waveforms. Therefore, another possible mechanism for the superior outcomes with burst waveforms can be insufficient amplitude applied for conventional tonic waveform SCS or paresthesia itself. Conventional tonic waveforms appear to induce paresthesia by increasing the spontaneous activity of gracile neurons in the dorsal column medial lemniscal system by delivering waveforms to the dorsal column.[28,29] Burst waveforms may affect the gracile nucleus in the dorsal column medial lemniscal system less due to the subthreshold stimulation of Aβ fibres at lower amplitudes.[25,30] Despite the lower amplitudes, burst waveforms can deliver higher charge per second than tonic waveforms by using a wide pulse width; and a large amount of charge is delivered to the dorsal column, which can manipulate spinal neural functioning.[31,32] Therefore, burst waveform SCS can suppress pain via the electrophysiological gate control mechanism before the clinical paresthesia threshold is reached. Painful or undesirable paresthesia is a reason for failed SCS trials.[33] In a previous study, 18.2% patients had painful or unpleasant sensations with conventional tonic waveform SCS.[20] In another study, many patients that were exposed to both tonic and burst SCS preferred burst waveforms due to the lack of paresthesia.[34] In a randomized controlled trial, 70.8% subjects

preferred burst waveforms over conventional tonic waveforms.[35] Furthermore, when asked about the primary reason for their preference for burst waveforms over conventional tonic waveforms, approximately 50% of the patients reported the lack of paresthesia.[35] Therefore, paresthesia has a significant effect on patients. This reduction in paresthesia may increase patient satisfaction and compliance and may ultimately help reduce pain.

In current case 1, the provocation in the pain area during trial lead insertion was not checked as is usual practice. This method may have had a negative impact on the accurate placement of the lead or the prediction of the result. Nevertheless, the pain area was very widespread throughout both arms and the lesion seen on MRI was expected to be the main cause of the pain. Considering the possible risks while placing a lead in patients with severe epidural adhesions, the procedure was performed under general anaesthesia. In addition, conventional tonic waveform SCS was not applied for a sufficient time in both patients because of the lack of pain reduction and discomforting tingling sensations. Because this is a case report, which includes only two cases and a retrospective design, it might be difficult to say that the different outcomes resulted from identical application of the two waveforms. Larger, controlled studies including patients with clearly defined indications and prognoses are necessary. Nevertheless, this small case series showed the possibility that burst waveform SCS is a good treatment option for patients with spinal cord injury and postamputation pain, which have not been highly recommended indications for SCS to date. Therefore, trials of new treatments such as dorsal root ganglion stimulation, high-frequency and closed loop SCS are also expected for pain indications previously known to have a poor prognosis.[36–38] Hopefully, these studies will provide the optimal treatment for patients with intractable pain.

In conclusion, this current case report has described the successful management of two cases of refractory upper limb pain after spinal cord injury and limb amputation using burst waveform SCS. Although the mechanism of burst waveform SCS is not fully understood, these current findings suggest that burst waveform SCS may have the potential to attenuate pain in patients with intractable pain. Therefore, burst waveform SCS should be studied to further evaluate its mechanism of action and efficacy.

Declaration of conflicting interest

The authors declare that there are no conflicts of interest.

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