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# Spinal Cord Stimulation for Complex Regional Pain Syndrome

Maneesh Shrivastav PhD, *Member, IEEE* and Shailesh Musley PhD

*Abstract*— **The therapy of spinal cord stimulation (SCS) is based on producing an electrical field on the dorsal surface of the spinal cord that blocks only neuropathic pain (ie, pain from damage to the nervous system). Most SCS devices deliver a biphasic pulse consisting of a pair of equal amplitude pulses with opposite polarity. SCS therapy is based on the gate control theory of pain and has been used for the treatment of diverse conditions of neuropathic pain, including complex regional pain syndromes (CRPS). In addition to CRPS, SCS is helpful in patients with failed back surgery syndrome, degenerative disk disease, and in patients with peripheral neuropathies. When used in the right patient, SCS provides significant pain relief in a majority of patients with CRPS. This review focuses on the effects of SCS on CRPS. In addition, an overview of the state of the art technologies used for implantable SCS medical devices is also provided.**

## I. Introduction

THE concept of spinal cord stimulation (SCS) was pioneered in the late 1960s by neurosurgeon Dr. Norman Shealy, who implanted the first dorsal column stimulator in a human suffering from terminal metastatic cancer. It is now widely used for a number of indications (over 14,000 SCS implantations occur annually world-wide [1]). SCS was first indicated as a treatment modality for the management of chronic, neuropathic, intractable pain generally for the trunk and/or limbs via delivery of electrical impulses to spinal segments. The treatment is not a cure, but a therapeutic option that can significantly reduce pain and improve the quality of life for most patients. Pain medication is often reduced for patients on SCS therapy [2].

Now in clinical use for over 40 years, SCS therapy has undergone significant evolution and technological advancement. Recent research and technical innovation has enabled applications of SCS to benefit various organ systems. Complex regional pain syndrome (CRPS) is a common use for SCS in the United States. CRPS is a painful disease (typically affecting a distal part of an extremity) that manifests sensory, sudomotor and vasomotor disturbances, and impaired motor function. It can also spread proximally and involve an entire limb (the upper limb is affected twice as often as the lower limb). It has a high impact on routine daily activities and negatively influences quality of life [3]. Patients describe the pain as a burning or itching sensation aggravated by movement of the limbs [4]. Other clinical features include allodynia, hyperalgesia, skin color changes, edema, stiffness of the joints, and bone demineralization over time [5, 6]. The diagnosis is based on history and physical examination, for which several diagnostic criteria are in practice. The nature of CRPS is puzzling, and the cause is not clearly understood. Women are more likely to be affected by CRPS than men are and treatment is most effective when started early in the course of the syndrome. CRPS occurs in two types with similar signs and symptoms, but different causes: Type I: Previously known as reflex sympathetic dystrophy (RSD) syndrome, this type occurs after an illness or injury that did not directly damage the nerves in the affected limb. About 90 percent of people with complex regional pain syndrome have type I. Type II: Once referred to as causalgia, this type follows a distinct nerve injury. Many cases of CRPS occur after a forceful trauma to an arm or a leg, such as a gunshot wound or shrapnel blast. Other major and minor traumas, such as surgery, heart attacks, infections, fractures and even sprained ankles, can also lead to CRPS. It is not well understood why these injuries sometimes trigger CRPS.

This review focuses on the effects of SCS on CRPS. In addition, an overview of the state of the art technologies used for implantable SCS medical devices is also provided.

## II. Mechanisms of Action for SCS

The clinical basis for pain management with SCS is derived from the gate control theory of pain, first introduced by Melzack and Wall in 1965 [7]. Neural mechanisms in the dorsal horns of the spinal cord act like a "gate" that can increase or decrease the flow of nerve impulses from peripheral fibers to the spinal cord neurons that project to the brain. Somatic input is therefore subjected to the modulating influence of the gate before it allows for pain perception (sensory cortex) and response (via limbic system). The theory suggests that large-fiber inputs tend to close the gate whereas small-fiber inputs generally open it. Furthermore, the sensory input is modulated at successive synapses throughout its projection from the spinal cord to the brain areas responsible for both pain experience and response [7]. The theory suggests that stimulation of dorsal columns would reduce or block the transmission of pain-related signals through the spinal cord. Moreover, SCS elicits paresthesia in the area innervated by the afferent nerve [8]. In essence, nonpainful stimuli can inhibit painful signals. This gate theory for pain has had significant impact on basic research and clinical developments. It has formed

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M Shrivastav is with Medtronic Neuromodulation, 7000 Central Ave NE, Minneapolis, Minnesota, 55432 USA (e-mail: maneesh@ ieee.org).

S Musley is with Medtronic Cardiac Rhythm Disease Management, 8200 Coral Sea Street NE, Minneapolis, Minnesota 55445 USA (e-mail: shaileshkumar.musley@medtronic.com).

the basis of the modern application of neuromodulation techniques for pain control.

The nerve fibers of the dorsal column serve as the stimulation target. Recruitment of fibers during stimulation is directly proportional to the diameter of the fiber and inversely proportional to the distance between the stimulation contact and the fiber [9]. Stimulation depends on the conductivity of the spinal elements in relation to the lead position. A neuron will propagate an action potential if it is made more electrically positive [10]. Thus, the fibers that respond to stimulation are closest to the cathode (-) since anodic stimulation does not occur under clinical conditions.

Most SCS devices deliver a biphasic pulse consisting of a pair of charge balanced pulses but with opposite polarity, as shown in figure 1. The biphasic waveform reduces tissue damage by balancing electrochemical reactions that occur during each phase. The effect of pulse width and inter pulse delay on action potential development has been studied elsewhere [11, 12].

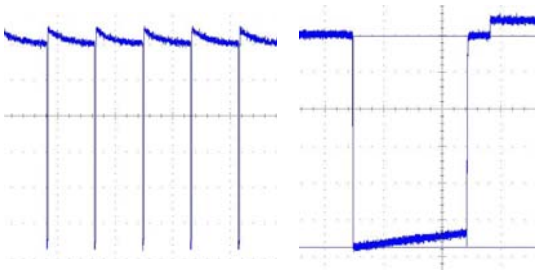

**Figure 1.** Stimulation waveform from a Medtronic RestoreULTRA™ SCS. The left waveform demonstrates the pulse train at a 60Hz rate. The right panel shows a magnification of one pulse with 10.5V amplitude and 390µs pulse width.

## III. SCS Implantable Devices

Candidate patients for SCS typically undergo a trialing procedure in which percutaneous leads are implanted with leads located in the epidural space on the dorsal aspect of the spinal cord. The lead is tunneled with the use of a Tuohy needle and connected to an external pulse generator for a trialing period. Patients then use a hand-held programmer to adjust the stimulation within set parameters to meet pain management needs. The trial period of stimulation lasts 4 to 7 days as the efficacy of treatment is assessed. If the patient has at least 50% improvement in pain during the trial, the patient is considered a candidate for the permanent unit. Kumar and colleagues found a 20% failure rate after trial stimulation for the treatment of chronic benign pain [6].

The goal of SCS is to generate an electric field that stimulates the relevant dorsal spinal cord structure and produce efficacious pain mitigation without stimulating the nearby nerve root [10]. To achieve efficacy, a usage range is determined. This is the interval between the perception threshold and the discomfort threshold. Physicians may employ active electrode screening techniques to achieve paresthesia by moving the lead and discovering the optimal range. Percutaneous leads are available in a number of electrode lengths and spacings. One lead can contain 4 or 8 electrodes, from 3mm to 6mm in length. The electrode spacing ranges from 4.5mm to 18mm (center to center) with diameter of approximately 1.3mm.

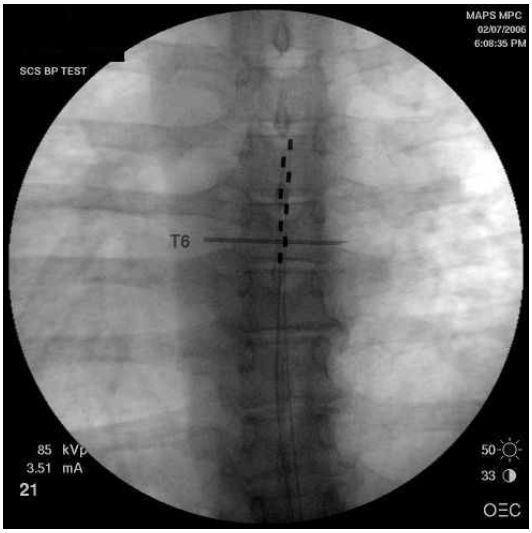


**Figure 2.** Fluoroscopic image of two quadripolar leads positioned in the thoracic region (T5/T6) of the spinal cord.

The stimulation settings are stored in programs that specify combinations of pulse width, rate, and amplitude settings acting on a specific electrode combination (multiple programs are available). Pulse amplitude can be set from 0 to 10.5V with 0.05V or 0.1V resolution. The pulse width can be adjusted from 60 to 1000µs with 10µs resolution. Pulse rate can be programmed from 2 to 1200Hz with resolutions as shown in Table 1. The recharge interval is 17 days at a medium setting.

TABLE I
STIMULATION FREQUENCY RANGE AND RESOLUTION

| Frequency Range (Hz) | Resolution (Hz) |
|---|---|
| 2-10 | 1 |
| 10-250 | 5 |
| 250-500 | 10 |
| 500-1000 | 20 |
| 1000-1200 | 50 |

Once candidacy is determined, the patient is implanted with a device. The implantable neurostimulator is a multi-programmable device that delivers stimulation through 1 or more leads. One such device, the Medtronic RestoreULTRA™ model 37712 [13], is a rechargeable 22cc system (54mm x 54mm x 10mm) with a lead containing up to 16 electrodes that is implanted in the lower back area (Figures 2 and 3). This device is indicated for a number of conditions as shown in Table II.

In a clinical setting, physicians use a variety of methods to determine the strength of electrical stimulation required. For example, the concept of paresthesia, a tingling or numbness that masks the painful stimuli, can be used to determine appropriate stimulation parameters [14, 15]. Typical values using this strategy range from threshold of paresthesia as reported by the patient, to twice this threshold [14]. In general, an intensity above this level is considered out of the patient comfort zone. It is important to note that such a threshold can be highly variable, and is dependent upon both electrode location and spinal geometry [14, 15]. Another method of determining stimulation values involves the monitoring of musculature motor thresholds of the receiving patient [16].

TABLE II
SCS INDICATIONS

| |
|---|
| • Failed Back Syndrome (FBSS) or low back syndrome or failed back |
| • Radicular pain syndrome or radiculopathies resulting in pain secondary to FBSS or herniated disk |
| • Post-laminectomy pain |
| • Multiple back operations |
| • Unsuccessful disk surgery |
| • Degenerative Disk Disease (DDD)/herniated disk pain refractory to conservative and surgical interventions |
| • Peripheral causalgia |
| • Epidural fibrosis |
| • Arachnoiditis or lumbar adhesive arachnoiditis |
| • Complex Regional Pain Syndrome (CRPS), Reflex Sympathetic Dystrophy (RSD), or causalgia |

Source: Medtronic Inc. 2009.

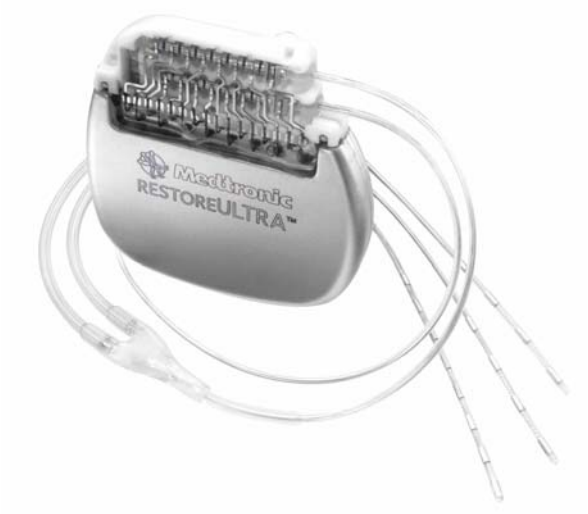


**Figure 3** Medtronic RestoreULTRA™ implantable spinal cord stimulator.

## IV. Clinical Studies of SCS for CRPS

In recent years, SCS has become increasingly successful in the long term due to refined patient selection criteria, greater accuracy in electrode placement, and improvements in multipolar and multichannel systems.

Forouzanfar *et al* [17] conducted a prospective study of 36 type I CRPS patients who had implanted SCS systems. The effectiveness of SCS was evaluated with mailed questionnaires at 6, 12 and 24 months after SCS implantation, with pain intensity being assessed on the visual analogue scale (VAS), and global perceived effect, and health related quality of life being assessed at those times. Results showed that at all of the follow-up periods, the pain intensity was significantly decreased.

Harke *et al* [5] conducted a retrospective study of 29 patients with type I CRPS. For all patients, pain medication and physical therapy had been ineffective for ≥ 1 year, and sympathetic block had produced only a temporary, positive response. The effectiveness of SCS was evaluated every 3 months after device implantation. Deep pain intensity was assessed and, allodynia, pain-related disability, drug consumption, functional status of the limbs, and return to work were determined at those times. Results showed that at 12-month follow-up, deep pain and allodynia on the VAS were significantly reduced. At a mean follow-up period of 35.6 ± 21 months, deep pain was at a median level of 2.0 cm (VAS) and allodynia had been completely abolished. Seventeen of the 29 (59%) patients did not require analgesic medications, and 16 (55%) patients were on low-dose tricyclic antidepressants to optimize activities of daily living. Overall, 70% of the patients had returned to work.

A randomized controlled trial [8] in type I CRPS patients showed that SCS therapy lead to a reduction in pain intensity at 24 months of follow-up (mean change in VAS score -2.0), whereas pain was unchanged in the control group (mean change in VAS score 0.0) ($p<0.001$). Taylor *et al* [8] also showed that 67% of type I and type II CRPS patients implanted with SCS reported pain relief of at least 50% over a median follow-up period of 33 months. There was also evidence to demonstrate that SCS is a cost-effective treatment for CRPS type I. Another recent review article by Albazaz *et al* [18] discusses the principles of management based on the limited available literature in the area. Kemler *et al* [19, 20], showed that SCS in combination with physiotherapy, or conventional treatment (only physiotherapy) was randomized among 54 patients with a diagnosis of RSD, of which 36 were submitted to SCS. Six months after implant there were significant differences in favor of the SCS-treated group in rated pain intensity. Several studies on SCS showed a potential beneficial effect of pain reduction in patients suffering from CRPS. Early recognition and a multidisciplinary approach to management are important in obtaining a good outcome.

## V. Conclusion: Efficacy of SCS Therapy for CRPS

Spinal cord stimulation provides neuromodulation of neuropathic pain signals and when used for appropriate indications in the right individuals, provides significant pain relief in patients trialed for efficacy [21]. The use of SCS has been shown to be highly effective in restoring normal function to affected limbs, especially if used early in the

course of the disease [22]. Studies have shown that SCS resulted in pain relief in a majority of patients with CRPS at a one year follow up period. The patients also reported a significant increase in quality of life [23]. SCS is an effective therapy in the management of patients with CRPS type I and type II.

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