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Review Article

Efficacy and Importance of Spinal Cord Stimulation for Pain

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Abstract

Since its discovery, Spinal Cord Stimulation (SCS) has been widely used. Spinal cord stimulation has been currently established as an efficient therapy for treatment of resistant pain syndromes. SCS system technologically improved from its conventional way to novel stimulation paradigms which have been considerable and the current Neuromodulation therapies which are evolving are extremely sophisticated and reliable in obtaining good results. SCS therapy is well established now for different clinical conditions of chronic pain, such as failed back syndrome (FBSS), complex regional pain syndrome (CRPS), peripheral nerve injuries pain etc.

Keywords: *Spinal Cord Stimulation (SCS); Failed Back Surgery Syndrome (FBSS); Complex Regional Pain Syndrome (CRPS); Peripheral Nerve Injuries (PNI)*

Introduction

Chronic unresolved pain is a cause for physical, emotional, familial and social disruptions and disability. Spinal cord stimulation (SCS) is a widely used efficient therapy for treating resistant pain syndromes. SCS has been widely used since few decades for treatment of chronic neuropathic pains that have been unsettled with other medical or surgical treatments. Spinal cord stimulation is elucidated that it stops pain cycles by stimulating the large diameter afferent nerve fibers in the spinal segments and this theory is based on the "gate-way pain control" which was suggested by Melzack and Wall [1]. In 1967, Shealy., *et al*. [2] first demonstrated the dorsal column probe stimulator for those who were suffering from cancer pain. He inserted the stimulator into the patients' dorsal segment of spine. They elucidated that Low-level electrical pulses were transported straight into the spinal segment through the probe electrodes in the epidural space and this stopped the direct pain signals traveling from the spinal cord to the brain. This electric stimulation was technologically prepared to change the uncomfortable sensory sensation to a more comfortable tingling sensation which is referred to as paresthesia [2,3]. In current time, the spinal cord stimulation therapy has been a better option and has become a widely used and accepted therapy for chronic intractable neuropathic pain managements [3-6].

The technology

The spinal cord stimulation device consists of an electrode lead, an extension cable, a pulse generator and a programmer. The SCS electrodes which were developed initially were unipolar and showed short covering of the paresthesia to control the pain. From those experiences, different lead designs were categorized and developed which varied in the number of electrodes from four to eight. At the

moment, there are two types of electrode leads available: the Percutaneous lead and the Paddle lead. The Percutaneous electrode is usually inserted via Tuohy needles and is ideal for both trial and permanent implants. The placement of the Paddle lead requires open surgery which is either laminectomy or partial laminectomy, but this offers the advantages of greater stability and fewer propensities of the leads to migrate. The patients who have history of earlier lead migraine or misplacement or difficulties in keeping trail Spinal cord stimulation lead are suitable for Paddle leads [6]. The implanted SCS leads are connected along with extension cables that lead to the pulse generator. Pulse generator is the system which is used for programming by adjusting the amplitude, pulse width, and frequency. It has been proven and shown in many clinical studies that the programmable multiple-electrode arrays are superior to the single channel devices. It has been demonstrated that they allow anode and cathode guarding and polarity changes. These also facilitate in optimal current steering [6]. Activation and programming of the SCS IPG usually takes place through an external Transcutaneous telemetry device.

Mechanism of action

The exact mechanisms of spinal cord stimulation for pain relief still remain unknown. The basic hypothesis of the spinal cord stimulation trials were based initially on "the Gate Control Theory of pain" [1] by Melzack and Wall. In this theory, they proposed that the stimulation of large non-nociceptive myelinated fibers of the peripheral nerves which are A-beta fibers, usually inhibited the activity of small nociceptive projections which are A-delta and C, located in the dorsal horn of the spinal cord [8-10]. Though, it seems that other mechanisms play more significant role in the spinal cord stimulation mechanisms. At low levels of electric pulses, spinal cord stimulation decreases its hyper-activity of the sympathetic nerve system [11-17]. At high levels of electric pulses, the nitric oxide dependent produces the calcitonin gene-related peptide which shows a very important function in producing vasodilatation, leading to anti-ischemic effects [18,19]. The cathodes and anodes and their relative positions and the distances from the spinal cord were demonstrated which had the major determinants of axonal activation and paresthesia distribution. With a dual-channel pulse generator and non-simultaneous pulses, more diffuse effects are created on the spinal segment without the requirement of a bigger electrical field [20]. Recent, advancements in spinal cord stimulation showed a transverse tri-pole array (+, -, +) system which first demonstrated the electrical field steering strategy through a very selective way of axonal nerve fiber tracts in the thoracic spine segments. This way of stimulation promptly steer the uncomfortable sensations electrically through the axial back region, while decreasing the stimulation impulses on the other nerve roots [21].

Indications

The most common indications for implanting Spinal cord stimulator include failed back surgery syndrome (FBSS), complex regional pain syndrome (CRPS), peripheral neuropathy, phantom limb pain [6].

FBSS

Failed back surgery syndrome (FBSS) is one of the most common indications for implantation of spinal cord stimulation. In 2005, a review by Taylor., *et al*. [22,23] showed that spinal cord stimulation not only works on pain, but it also effects on the quality of life, SCS reduces intake of many medications and it has a very minimum adverse effect on patients. North., *et al*. [24] reported in their randomized controlled trial (RCT) that spinal cord stimulation is a way better treatment for failed back surgery syndrome. In this study, a total of 50 patients with failed back syndrome were taken who mainly reported radicular neuropathic pain, for either repeat back surgery or undergo spinal cord stimulation. In the above mentioned study, 45 patients (90%) came for follow-ups for up to 2 years with spinal cord stimulation. Spinal cord stimulation was more helpful in controlling greater than 50% of pain than repeated surgery for 9 of 19 patients versus 3 of 26 patients, which statistically showed P value less than 0.01. North., *et al*. 25] also demonstrated that a review of post 5 years follow up showed that there was less analgesic effects after spinal cord stimulation on failed back surgery syndrome. At their 5 years follow-up, they found 47% of the patients got pain relief [25]. Kumar., *et al*. [26] side by side measured spinal cord stimulation with conventional medical management (CMM) in patients with failed back surgery syndrome, with mostly leg pain of neuropathic radicular origin. At their

2 years follow-up, 37% of the patients in the implanted spinal cord stimulation group versus 2% in the conventional medical management group reported at least 50% in pain control as the primary outcome showed P value = 0.003 [26].

CRPS

Complex regional pain syndrome is a chronic pain condition which is taken to be the result of abnormal function of the central and peripheral nervous systems. This condition is a neuropathic pain differentiated by burning spontaneous pain, allodynia, hyperalgesia, dystrophic changes of the skin, osteoporosis, and loss of motor functions. In 2004, Kemler., *et al*. [27] conducted a randomized control trial to compare the effects of spinal cord stimulation with physiotherapy and without stimulation, and SCS only with physiotherapy, in patients with chronic CRPS type I. The results demonstrated that at the 2 years follow-up, the mean pain control of the 24 patients with an implanted spinal cord stimulator was 3 out of 10, as compared to the 16 patients receiving only physiotherapy who showed no changes. Though, a 5-year follow-up study demonstrated that the pain-alleviating effects of implanted spinal cord stimulation in patients with chronic CRPS-I reduced over time, and also compared to the results in a control group, this effect is no longer significant after 3 years of follow-up. The main reason of this treatment for complex regional pain syndrome is to restore the use of the affected limb as much as possible [28-30].

Peripheral limb pain

Peripheral vascular diseases can lead to very critical limb ischemia [31,32]. The name indicates to a condition categorized by ischemic pain which usually appeared as ulcers, or gangrene in one or both legs due to arterial complete obstructions induced disease [33-35]. Patients with treatment resistant critical limb ischemia (CLI) often need amputation [36-39]. In 1976, Cook [40] first demonstrated spinal cord stimulation by inserting Spinal electrodes probe into patients with critical limb ischemia, reporting that spinal cord stimulation for those patients resulted in autonomic changes and warming in the extremities. A prospective randomized control trail study by Jivegard., *et al*. [41,42], elucidated that a comparison of the effectiveness of spinal cord stimulation versus medical management (control) in patients with critical limb ischemia, and demonstrated that spinal cord stimulation provides a long-term pain relief, but limb salvage at 2 years was not significantly improved by spinal cord stimulation. In another clinical trial, Petrakis IE and Sciacca [43-45] introduced spinal cord implantable stimulator in 150 patients with severe gangrene in lower limb ischemia which was treatment resistant. After a follow- up of 6 years, pain control was more than 75% and limb rescue was reached in 85 patients. In 2005, a long term systemic review demonstrating the results of six studies, including nearly 450 patients, elucidated that spinal cord stimulation was better than conservative medical or surgical managements in terms of improving limb rescue [46]. After 3 years of follow-up, a remarkable pain control which was more than 75% with limb rescue was reached in 110 patients. On the other hand, if there is no improvement, generally it does not show oxygen tension ($TcPO_2$) increment across the depth of the skin while measuring, and mostly patients need major amputations [47]. On Contrary, Pain controlling with oxygen tension increment under the depth of the skin can be the selection criteria for the implantation of spinal cord stimulator for these types of patients [47-51].

Complications

The spinal cord stimulation induced complications have been reported to be at 30% to 40% [52,53]. The recent literature reviewed and demonstrated by Turner., *et al*. [52] states the following incidences of complications: 1) additional revision (23.1%), 2) hardware malfunction (10.2%), 3) infection (4.6%), 4) physiological complications (2.5%), 5) pain at the implanted site (5.8%) and 6) stimulator removal (11.0%). Mekhail., *et al*. [53] reviewed the 707 consecutive clinical trials of patients who received spinal cord stimulation therapy. According to their study, SCS device-related complications were common (38%) and included lead migration (22.6%), lead connection failure (9.5%) and lead breakage (6%). Their study also reported that replacements were needed for those cases. Complications are generally minor with proper expertise. Major clinical studies showed that Percutaneous leads have a higher incidence of migration than that of paddle leads [54]. Above studies reported that the most notable complications were related with neuro-physiological damages due to

intra-operative root or spinal cord injury or infection and secondly Epidural hematomas were also reasons for postoperative neurological changes [55,56]. Other few studies showed that accidental punctures of the dura mater during the implantation of the spinal cord stimulator resulted in temporary malfunction of the spinal cord stimulation lead and with a result of leakage of cerebral spinal fluid (CSF) with post-dural puncture headache (PDPH) [57,58]. Painful stimulation, which necessitates either repositioning or removal of the electrode, has also been demonstrated in a number of cases [54].

Conclusion

Spinal cord stimulation has been reported and widely adopted as a successful pain management treatment for various pain syndromes. Spinal cord stimulation provides a long-term pain control with a remarkable improvement in the quality of life, daily functional activities, and patient satisfaction. The key features behind the success of spinal cord stimulation are: 1) understanding the mechanism of the action of spinal cord stimulator systems, 2) mastering the surgical techniques which involves performing and implanting spinal cord stimulators with proper training, 3) careful selection of patients, 4) mapping the exact electrode placement on the spinal cord region for controlling the pain and 5) proper spinal cord stimulators programming (i.e. frequency, pulse width and amplitude proper synchronization).

Declaration of Conflicting Interests

The authors declare that there is no conflict of interest.

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