Epidural electrical spinal cord stimulation

- Epidural electrical stimulation facilitates motor recovery in spinal cord injury involving the conus medullaris: A case study
- Nanogenerator Neuromodulation to Enable Locomotion Rehabilitation for Spinal Cord Injury via Epidural Electrical Stimulation
- Role of frequency-dependent and capacitive tissue properties in spinal cord stimulation models
- Atypical Applications of Neuromodulation for Non-Painful Conditions
- Redistribution of Intraspinal and Muscular 18 F-FDG Uptake after the Epidural Electrical Stimulation Treatment in Spinal Cord Injury Individuals
- Chronic, Battery-Free, Fully Implantable Multimodal Spinal Cord Stimulator for Pain Modulation in Small Animal Models
- Spinal Cord Stimulation Failed to Improve Parkinson's Disease Symptoms in Randomized Crossover Double-Blinded Evaluation
- Transtraumatic Epidural Electrostimulation Promotes the Preservation of the Spinal Cord and Skeletal Muscles in Pigs

Spinal cord stimulation (SCS) is a common intervention for managing intractable pain. Generally, leads are implanted in a minimally invasive procedure with verbal feedback regarding the location and nature of generated paresthesias by active stimulation.

Since its introduction in the late 1960s [1)], epidural Electrostimulation of the dorsal columns of the spinal cord, commonly referred to as spinal cord stimulation (SCS), has been used frequently for the treatment of chronic pain.

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Spinal cord stimulation has emerged as a state of the art evidence based treatment for chronic neuropathic pain and mixed nociceptive-neuropathic pain. Several newer devices and treatment algorithms have provided unique and effective ways of treating chronic pain by spinal cord stimulation. In a previous review, Maheshwari et al., from University Hospitals Cleveland Medical Center, Evolve Restorative Center, Santa Rosa, The Spine and Nerve Centers of Virginia, Functional

Neurosurgery St. Luke's University Hospital Bethlehem , commented on the five-year forecast for high frequency and Burst wave forms, as the only two paresthesia independent SCS strategies. Over the last five years there has been considerable addition to the outcome data related to these modalities. Additionally, new treatment algorithms and modalities for spinal cord stimulation have emerged.

In a new review, they provided an up to date summary of these modalities of treatment, indications and evidence on all different modalities and programming paradigms that are available today.

A literature review was performed using key bibliographic databases to find outcomes related studies pertaining to spinal cord stimulation, limited to the English language and human data, between 2010-18. The literature search yielded the following based on there inclusion criteria; six articles on burst stimulation, three articled on high density/high dose stimulation, six articles on Dorsal Root Ganglion stimulation, nine articles on high-frequency stimulation and one article on closed loop stimulation.

They also included in the discussion some smaller and anecdotal studies.

The evidence to support outcomes of spinal cord stimulation has evolved considerably since the last review in 2014. New targets, frequencies and pulse trains, and feedback appear to have advanced the efficacy of spinal cord stimulation. Future developments aim to continue to refine patient selection and maintenance of patients in therapy [2].

Mechanism of action

Our traditional understanding of how spinal cord stimulation (SCS) works relies on gate control theory.

How spinal cord stimulation (SCS) in its different modes suppresses pain is poorly understood. Mechanisms of action may reside locally in the spinal cord, but also involve a larger network including subcortical and cortical brain structures. Tonic, burst, and high-frequency modes of SCS can, in principle, entrain distinct temporal activity patterns in this network, but finally have to yield specific effects on pain suppression. Here, we employ high-density electroencephalography (EEG) and recently developed spatial filtering techniques to reduce SCS artifacts and to enhance EEG signals specifically related to neuromodulation by SCS.

Materials and methods: We recorded high-density resting-state EEGs in patients suffering from pain of various etiologies under different modes of SCS. We established a pipeline for the robust spectral analysis of oscillatory brain activity during SCS, which includes spatial filtering for attenuation of pulse artifacts and enhancement of brain activity potentially modulated by SCS.

Results: In sensor regions responsive to SCS, neuromodulation strongly reduced activity in the theta and low alpha range (6-10 Hz) in all SCS modes. Results were consistent in all patients, and in accordance with the thalamocortical dysrhythmia hypothesis of pain. Only in the tonic mode showing paresthesia as side effect, SCS also consistently and strongly reduced high-gamma activity (>84 Hz).

Conclusions: EEG spectral analysis combined with spatial filtering allows for a spatially and temporally specific assessment of SCS-related, neuromodulatory EEG activity, and may help to disentangle therapeutic and side effects of SCS [3].

Classification

High-frequency spinal cord stimulation

see Cervical spinal cord stimulation.

see Burst stimulation.

Indications

see Spinal cord stimulation indications.

Technique

Spinal cord stimulation surgical technique.

Outcome

Spinal cord stimulation outcome

Studies

PROSTIM study

Prospective observational cohort studies

Spinal cord stimulation is a possible treatment option for pain management; however, patients undergoing this intervention require close follow-up, which is not always feasible. eHealth apps offer opportunities for improved patient follow-up, although adherence to these apps tends to decrease over time, with rates dropping to approximately 60%. To improve adherence to remote follow-up, we developed a remote follow-up system consisting of a mobile app for patients, a website for health care professionals, and a remote support center.

The objective was to evaluate patient adherence to remote follow-up using a system that includes a mobile app and a remote support center.

After review of the literature and approval of the design of the follow-up system by a multidisciplinary committee, a team of experts developed a system based on a mobile app, a website for health care professionals, and a remote support center. The system was developed in collaboration with health care professionals and uses validated scales to capture patients' clinical data at each stage of treatment (ie, pretreatment phase, trial phase, and implantation phase). Data were collected prospectively between January 2020 to August 2023, including the number of total surveys sent, surveys completed, SMS text message reminders sent, and reminder calls made.

A total of 64 patients were included (n=40 women, 62.5%) in the study. By the end of the study, 19 (29.7%) patients remained in the pretreatment phase, 8 (12.5%) patients had completed the trial phase, and 37 (57.8%) reached the implantation phase. The mean follow-up period was 15.30 (SD 9.43) months. A total of 1574 surveys were sent, along with 488 SMS text message reminders and 53 reminder calls. The mean adherence rate decreased from 94.53% (SD 20.63%) during the pretreatment phase to 65.68% (SD 23.49%) in the implantation phase, with an overall mean adherence rate of 87.37% (SD 15.37%) for the app. ANOVA showed that adherence was significantly higher in the earlier phases of treatment (P<.001).

The remote follow-up system, supported by a remote support center improves adherence to follow-up in later phases of treatment, although adherence decreased over time. Further studies are needed to investigate the relationship between adherence to the app and pain management [4)].

This study represents an important step in understanding the role of eHealth in managing SCS follow-up. While it demonstrates the potential to improve adherence, it leaves key questions unanswered regarding the relationship between adherence and clinical outcomes. Addressing these gaps in future research could significantly enhance the design and implementation of remote follow-up systems, ensuring both patient engagement and improved clinical care.

Case series

Spinal cord stimulation case series

Case reports

Stone LE, Falowski SM. Pre-Operative Imaging for Spinal Cord Stimulation: A Case Report of a Spinal Cord Tumor Identified by Screening Magnetic Resonance Imaging of the Thoracic Spine. Neuromodulation. 2018 Sep 13. doi: 10.1111/ner.12848. [Epub ahead of print] PubMed PMID: 30211964.

1)
Shealy CN, Mortimer JT, Reswick JB. Electrical inhibition of pain by stimulation of the dorsal columns: preliminary clinical report. Anesth Analg. 1967 Jul-Aug;46(4):489-91. PubMed PMID: 4952225.

2)
Maheshwari A, Pope JE, Deer TR, Falowski S. Advanced methods of spinal stimulation in the treatment of chronic pain: pulse trains, waveforms, frequencies, targets and feedback loops. Expert Rev Med Devices. 2019 Jan 9. doi: 10.1080/17434440.2019.1567325. [Epub ahead of print] PubMed PMID: 30625000.

3)
Buentjen L, Vicheva P, Chander BS, Beccard SA, Coutts C, Azañón E, Stenner MP, Deliano M. Spatial Filtering of Electroencephalography Reduces Artifacts and Enhances Signals Related to Spinal Cord Stimulation (SCS). Neuromodulation. 2020 Sep 24. doi: 10.1111/ner.13266. Epub ahead of print. PMID:

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4)

Gómez-González MA, Cordero Tous N, De la Cruz Sabido J, Sánchez Corral C, Lechuga Carrasco B, López-Vicente M, Olivares Granados G. Following Up Patients With Chronic Pain Using a Mobile App With a Support Center: Unicenter Prospective Study. JMIR Hum Factors. 2025 Jan 22;12:e60160. doi: 10.2196/60160. PMID: 39844381.