

Development of a Questionnaire to Assess Epidural Stimulation Usage by Individuals with Spinal Cord Injury

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Abstract

Over the last decade, several pilot phase clinical trials of electrical stimulation, applied to the dorsal surface of the spinal cord, in individuals with spinal cord injury (SCI) have shown that SCI-related sensorimotor and autonomic dysfunction can be improved via rehabilitation with epidural stimulation (ES). To deliver ES, clinical trial participants undergo surgical placement of stimulating electrodes within the spinal canal which are connected to an implanted pulse generator. Upon completion of clinical trial activities, the electrodes and pulse generator typically remain implanted and fully functional, however, there is a lack of information available regarding the extent to which ES usage is continued, and functions gained, by individuals with SCI. Our objectives are to develop a tool to measure community usage of ES by individuals with SCI, and corresponding performance changes within each participant, that can be widely used by institutions using ES. We have developed an online questionnaire for individuals with SCI who have undergone implantation of an ES system with the intent of improving SCI-related impairments. The questionnaire remains active and is globally accessible via the QualtricsSM application (Qualtrics, Provo, UT).

Keywords: Spinal cord injury, SCI, Epidural stimulation, Spinal cord stimulation, Epidural stimulation questionnaire, Epidural stimulation survey, Epidural stimulation usage

Introduction

Currently, in the United States alone an estimated 300,000 people are living with spinal cord injury (SCI), with approximately 17,000 new cases occurring each year [1]. Unfortunately, there is no known cure for SCI, and therefore, lifelong motor and sensory deficits and autonomic dysfunctions are expected after severe SCI. In addition to its devastating impact on quality of life, analyses indicate lifelong healthcare costs range from \$2,000,000 to \$5,000,000 per patient, depending on age of onset and severity of injury [1].

Emerging therapies, including neuromodulation of the spinal cord using electrical spinal stimulation, more often referred to as epidural stimulation (ES), have been demonstrated to

comprehensively enable functions typically impaired due to SCI. These include bowel, bladder, and sexual function, as well as motor activity, including standing [2-7] and stepping abilities [5,6,8]. Additionally, cardiovascular recovery and blood pressure regulation have been reported to be achieved through ES [9-11].

ES used within the clinical research setting involves the application of electrical stimulation directly to the lower part of the spinal cord below the level of injury. An electrode array is surgically implanted on the dura of the spinal cord with the potential to activate spinal sensorimotor networks to enable functionality of specific body systems, dependent on directed research outcomes. The Food and Drug Administration (FDA) approval for ES is currently limited to the treatment of chronic

pain. Approved treatment for impairments related to SCI include but are not limited to motor function, autonomic regulation and bladder function await successful clinical trial data and submission for review. However, research centers across the globe continue to generate promising results that indicate strong potential of ES as an effective therapeutic tool to recover function after SCI [13].

At the time of submission, (2023), 45 studies including the key words 'spinal cord injury' and 'epidural stimulation' were identified on clinicaltrials.gov. During ES study participation, stimulation programs are adjusted for a specific functionality and further individualized to each participant. Upon study completion, participants have free use of the ES device for its remaining useful life, albeit with limited configuration options. Typically access to full programming is restricted to clinicians, who would have the capability and knowledge base for modifying specific stimulation parameters. Specifically, there is a need to understand how individuals with SCI integrate the use of ES in their daily life. There is a paucity of information regarding participant usage at home and in the community after implantation and study completion. Implementing follow up questionnaires will allow i) identification of the number of individuals implanted, who are no longer enrolled in active trials, ii) review the usage of their device, and iii) unmask the functionality, or daily use, enabled by the limited device parameters. Altogether, this information will give better perspective of how ES can be used and the effects it has on daily life, if and when the treatments become widely available for the indication of SCI [14].

There has been limited translation of user experience from participants with SCI and their use of implanted stimulation devices following study completion. In 2003, a survey was completed by Case Western Reserve University/Veterans Affairs that assessed individuals with SCI who had been implanted with a stimulation device addressing usage patterns, performance, satisfaction, complications, and health benefits related to an implanted neuroprosthetics intended for standing exercise and transfers [15]. The study reported that 9 of 11 participants were using the device regularly at the time of the survey. Additionally, all participants reported improved health and reduced incidences of pressure sores, spasticity, and urinary tract infections due to stimulation use. A separate longitudinal study completed between multiple institutions assessed 15 participants with SCI, also regarding an implanted stimulation device, which showed that usage reported over the one-year period remained constant; however, more time was spent using the device for daily activity than during an exercise program. Physical performance change was not statistically significant from discharge to follow up for these individuals. Electrode stability was reported, indicating survivability of the device, meaning minimal changes in stimulation thresholds, which remained greater than 90% [16].

Initiatives at SCI symposia as well as related funding

agencies have recognized that ES user experience from the SCI community will give way to research directions that will have the greatest impact on desired restoration of function. Additionally, translation of information related to clinical research is best received by the community when it comes from those with lived experience. In 2008, a panel discussion was held at the Neural Interfaces Conference, inviting those living with SCI to assist in identifying priorities of functional return that may be gained by using neuroprosthetics. Priorities that crossed over between those living with tetraplegia and paraplegia emphasized recovery of bowel, bladder, and sexual function [17]. In 2020, the National Institute of Health (NIH) hosted a conference titled "SCI 2020: Launching a Decade of Disruption in Spinal Cord Injury Research" [18]. This conference also brought together stakeholders within the field of SCI, including persons with SCI, industry partners, regulators, and funding agency representatives in attempt to bridge the gap of communication from all relevant perspectives. During this conference, six identified topics were discussed at length during dedicated sessions, including ES to improve neurological function months and years after SCI. Overall, recommendations identified during this session considered inclusion and/or enrolling persons with chronic SCI, as lived experience can inform practicality and meaningfulness of the data set/outcomes while delivering ES. Also, attendees emphasized the necessity of longitudinal studies to measure sustainability and accessibility. Tracking longitudinal data that impacts each person individually is more generalizable than current prospective research methods. A survey could potentially fulfill this need allowing stakeholder to capture a broad range of outcomes that assess several body structures and functions. Additionally, return to work, quality of life and social participation are also necessary to assess in order to understand the full impact of the intervention even once the research is complete.

A gap in the literature exists for an understanding of the individualized long-term use of ES, intended to improve specific functionality, and the potential advantages and disadvantages of this invasive therapy. *Here, we report the development of a questionnaire to assess daily use of ES in individuals with SCI apart from clinical trial enrollment.* The development of this questionnaire is intended to provide a direct perspective from individuals with SCI of ES from independent, non-directed use. Information gained from this tool can help stakeholders understand the implications including facilitators and barriers associated with utilizing ES today. Continued assessment of individuals with already implanted ES systems provides the SCI community with a unique opportunity to track longitudinal information that can help facilitate future needs and limitations of this technology without extraneous financial burden to all stakeholders. Additionally, the positive and negative aspects of ES use and the impacts on each person individually, is more generalizable than current prospective research methods.

Objectives and Specific Aims

Our objective is to introduce a questionnaire for individuals with SCI that have participated in ES implantation to gather perceived benefits from ES, device type or model details, and functionality gained with use of ES. The questionnaire is available in written form and can be shared electronically through web access for versatile utility.

Materials and Methods

Description of study population

The questionnaire is applicable for individuals with SCI who have received a permanent epidural spinal stimulation implant and are English speaking. This questionnaire is available at any time and may be applied to specific study participants. For development of this questionnaire, this study was reviewed by our IRB and deemed exempt from full review due to intention to collect only deidentified data. For comparing integrating individualized data sets, IRB approval may be required.

Description of questionnaire development

The questionnaire, titled: ***Epidural Stimulation Usage Survey for Individuals with Spinal Cord Injury*** is intended to assess the usage of ES during various activities of daily living. The questionnaire went through several iterations with the study team as well as discussions with community advocates who have had successful questionnaires within the SCI community. We shared the purpose of the survey and were offered feedback on areas to focus. We collaborated with experts at our institution who specialize in the development of questionnaires to ensure we use proper question structure to adequately capture the goals and usage of ES in the SCI community. We intend to respectfully ask questions and honestly report the outcomes of ES use following study participation. The questionnaire consists of maximum of 88 questions in the online version (please reach out to mnsicare@mayo.edu for survey preview), 77 questions in the paper adaptation (Supplementary 1), and is sectioned into specific domains. The six domains comprehensively explore the how and why ES is used for each participant. The questionnaire begins with outlining the participant's background, their SCI profile which includes American Spinal Injury Association Impairment Scale classification of injury, time since injury and age at time of injury. Information related to the participant's need for assistive devices when not using stimulation is also collected.

Questionnaire domains include (1) ES use, (2) motor response from ES, (3) use of ES in the community, (4) sensory response (pain/spasticity), (5) autonomic response (bowel, bladder, sexual functions, and heart rate and blood pressure), (6) demographics and open user experience questions (**Table 1**).

(1) **ES use:** The first block of questions asks about routine use

of ES, which therapies are paired with ES for therapeutic benefit (locomotor training, stem cells, transcranial magnetic stimulation, exoskeleton training, functional electrical stimulation), and request for subjective (fill in) response in frequency and duration/type of activity. The questionnaire also captures stimulation usage (duration and time of day) and any related complications. Details on the type of stimulator are collected including brand, model, and array design.

- (2) **Motor response during ES:** Motor responses and functional tasks related to activities of daily living (ADLs) are included to better understand activities enabled by ES. Motor responses include upper extremity and lower extremity movement, trunk/posture assist, stepping, and standing. Participants are asked to rank the motor responses most desired when using ES and to rate their performances with and without ES. Similarly, participants are asked to rate how well they perform common ADLs with and without ES. Performance rating is based on a Likert scale (unable, poor, fair, good, excellent, not applicable).
- (3) **Use of ES in the community:** Exercise related activities performed in the community setting, are detailed with and without the use of ES. If there is no exercise performed in the community, questions related to barriers that are preventing participation, such as availability of adaptive equipment, are addressed.
- (4) **Sensory response (pain/spasticity):** Questions specifically related to pain and spasticity target sensory responses. Pain questions inquire about type of pain (skin, nerve, muscle, joint), location on the body, and preferred treatment options. Spasticity questions aim to determine if there is an increase or decrease in spasticity while using ES, or after using ES, and if that is a positive or negative outcome for the individual.
- (5) **Autonomic response (Bowel, bladder, sexual functions, and cardiovascular function):** Participants are asked if ES has an impact on autonomic functions, specifically, bowel, bladder, sexual function, and regulation of cardiovascular function. If stimulation is not used for any of these functions this block of questions will be skipped. For bowel and bladder function, specific details regarding duration and, frequency of voiding, and incontinence episodes are gathered. Likewise, questions related to satisfaction and ability to achieve climax and/or orgasm are asked to understand ES impact on sexual function. Participants are requested to describe cardiovascular responses specific to heart rate and blood pressure with and without ES.
- (6) **Demographics and open user experience:** Demographic information such as sex at birth, gender, race, and current age is collected. Socioeconomic status

and the impact on livelihood and employment based on the use of ES is addressed. The final questions address subjective feedback on perceptions of ES. This open field entry allows participants to rank the importance of functions in terms of quality of life, recommendations for future studies in ES, and overall positive and negative perspectives on ES. Lastly, we ask for any feedback to improve the questionnaire itself.

Table 1.	
Domains	Description
Background (Injury classification)	
1. Epidural Stimulation Use	Mobility with and without ES
	Complications
	Complimented with other treatments
	ES brand, model, array
	ES usage, duration, timing,
2. Motor Response from Epidural Stimulation	Functional tasks with and without ES
	Performance rating with and without ES
3. Community Use	Exercise, recreational based activities, etc.
4. Sensory	Pain - type, location, treatment options
	Spasticity - ES influence
5. Autonomic	Bowel - duration, frequency, incontinence
	Bladder - duration, frequency, incontinence
	Sexual function - satisfaction, climax/orgasm
	Cardiovascular response - Heart rate, blood pressure
6. Socioeconomic Demographics Other recommendations	ES effect on livelihood and employment
	Age, gender, race
	Ranking functions for QOL
	Recommend for future patients
	Overall positive/negative changes
	Survey feedback

Once the layout was complete, the Mayo Clinic Survey Research Center was contacted to assist in review of question logic and responses. Once each question had been evaluated for a specific set of responses, the completed questionnaire was converted to a digital platform. The Qualtrics^{XM} application

was used to transform the questionnaire to a digital interface for ease of distribution. Of note, we have surveyed a small group of individuals with ES implants to assess usability of the survey, all questions were answered appropriately given the context of questions. This user experience questions are intended to drive forward the field of research in ES through the understanding we may gain from those with personal, long term experience.

Discussion

Questionnaires can be incredibly useful; however, they do present general limitations to clinical translation. First, the SCI population is a heterogeneous population, focusing on a specific subset of individuals (ES implanted) impacts generalization. Second, questionnaires have limited response options which may not fully capture the usability of ES across all individuals. Third, a bias of what functional tasks each person with an ES device has access to may be heavily influenced by the research study they participated in previously. Given the non-FDA approved indication for ES in the SCI population beyond chronic pain, clinical programming is not available impacting the access to ES refinement. Finally, it is necessary to assess the number of respondents needed to determine clinical impact provided by this questionnaire.

Next Steps

Through this publication, the written version of the questionnaire is available within the supplementary material (Supplementary File 1). The availability of the Qualtrics^{XM} application will require sites to have an account within the platform for the electronic questionnaire to be shared directly from Mayo Clinic, via email request (mnscicare@mayo.edu). Each entity/research study may collect data specific to their participants. The questionnaire may be paired with identifying information for a more comprehensive review of individual cases. The survey may also be adapted by providing an individualized link through direct email. This option will allow the user to close the survey, having saved information, and restart at a later time. This will accommodate any participant fatigue. Both written and digital questionnaires will be available through this publication at no cost. When used widely we will gain perspective from those using ES after trial participation and be able to better inform the SCI community interested in the therapy.

Data Repository

Once implemented, electronic data collected from this survey is stored within the Qualtrics system and available for export via CSV (text or numeric values) for post analysis.

Disclosures

Authors have no financial or ethical conflicts of interest to declare.

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Data

No data has been collected in the development of this manuscript.

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Author Contributions

Conceptualization and methodology: Kristin Zhao, Margaux Linde, Megan Gill, Daniel Veith, Peter Grahn. Writing and original draft preparation: Margaux Linde. Visualization and application: Margaux Linde, Megan Gill, Daniel Veith, Crystal Whitmarsh. Supervision: Kristin Zhao. Writing, reviewing, editing: Megan Gill, Daniel Veith, Lisa Beck, Crystal Whitmarsh, Peter Grahn, Andrew Thoreson, Rena Hale, Carmen Terzic.

References

1. National Spinal Cord Injury Statistical Center. Spinal Cord Injury Facts and Figures at a Glance. *J Spinal Cord Med.* 2014 May;37(3):355-6.
2. Rejc E, Angeli C, Harkema S. Effects of Lumbosacral Spinal Cord Epidural Stimulation for Standing after Chronic Complete Paralysis in Humans. *PLoS One.* 2015 Jul 24;10(7):e0133998.
3. Rejc E, Angeli CA, Bryant N, Harkema SJ. Effects of Stand and Step Training with Epidural Stimulation on Motor Function for Standing in Chronic Complete Paraplegics. *J Neurotrauma.* 2017 May 1;34(9):1787-802.
4. Grahn PJ, Lavrov IA, Sayenko DG, Van Straaten MG, Gill ML, Strommen JA, et al. Enabling Task-Specific Volitional Motor Functions via Spinal Cord Neuromodulation in a Human With Paraplegia. *Mayo Clin Proc.* 2017 Apr;92(4):544-54.
5. Gill ML, Grahn PJ, Calvert JS, Linde MB, Lavrov IA, Strommen JA, et al. Neuromodulation of lumbosacral spinal networks enables independent stepping after complete paraplegia. *Nat Med.* 2018 Nov;24(11):1677-82.
6. Wagner FB, Mignardot JB, Le Goff-Mignardot CG, Demesmaeker R, Komi S, Capogrosso M, et al. Targeted neurotechnology restores walking in humans with spinal cord injury. *Nature.* 2018 Nov;563(7729):65-71.
7. Lin A, Shaaya E, Calvert JS, Parker SR, Borton DA FJ. A Review of Functional Restoration From Spinal Cord Stimulation in Patients With Spinal Cord Injury. *Neurospine.* 2022;19(3):735-6.
8. Angeli CA, Boakye M, Morton RA, Vogt J, Benton K, Chen Y, et al. Recovery of Over-Ground Walking after Chronic Motor Complete Spinal Cord Injury. *N Engl J Med.* 2018 Sep 27;379(13):1244-50.
9. Harkema SJ, Legg Ditterline B, Wang S, Aslan S, Angeli CA, Ovechkin A, et al. Epidural Spinal Cord Stimulation Training and Sustained Recovery of Cardiovascular Function in Individuals With Chronic Cervical Spinal Cord Injury. *JAMA Neurol.* 2018 Dec 1;75(12):1569-71.
10. Harkema SJ, Wang S, Angeli CA, Chen Y, Boakye M, Ugiliweneza B, et al. Normalization of Blood Pressure With Spinal Cord Epidural Stimulation After Severe Spinal Cord Injury. *Front Hum Neurosci.* 2018 Mar 8;12:83.
11. West CR, Phillips AA, Squair JW, Williams AM, Walter M, Lam T, et al. Association of Epidural Stimulation With Cardiovascular Function in an Individual With Spinal Cord Injury. *JAMA Neurol.* 2018 May 1;75(5):630-2.
12. Calvert JS, Grahn PJ, Strommen JA, Lavrov IA, Beck LA, Gill ML, et al. Electrophysiological Guidance of Epidural Electrode Array Implantation over the Human Lumbosacral Spinal Cord to Enable Motor Function after Chronic Paralysis. *J Neurotrauma.* 2019 May 1;36(9):1451-60.
13. Thorogood NP, Waheed Z, Chernesky J, Burkhart I, Smith J, Sweeney S, et al. Spinal Cord Injury Community Personal Opinions and Perspectives on Spinal Cord Stimulation. *Top Spinal Cord Inj Rehabil.* 2023 Spring;29(2):1-11.
14. Solinsky R, Specker-Sullivan L, Wexler A. Current barriers and ethical considerations for clinical implementation of epidural stimulation for functional improvement after spinal cord injury. *J Spinal Cord Med.* 2020 Sep;43(5):653-6.
15. Agarwal S, Triolo RJ, Kobetic R, Miller M, Bieri C, Kukke S, et al. Long-term user perceptions of an implanted neuroprosthesis for exercise, standing, and transfers after spinal cord injury. *J Rehabil Res Dev.* 2003 May-Jun;40(3):241-52.
16. Triolo RJ, Bailey SN, Miller ME, Rohde LM, Anderson JS, Davis JA Jr, et al. Longitudinal performance of a surgically implanted neuroprosthesis for lower-extremity exercise, standing, and transfers after spinal cord injury. *Arch Phys Med Rehabil.* 2012 May;93(5):896-904.
17. French JS, Anderson-Erisman KD, Sutter M. What do spinal cord injury consumers want? A review of spinal cord injury consumer priorities and neuroprosthesis from the 2008 neural interfaces conference. *Neuromodulation.* 2010 Jul;13(3):229-31.
18. Morse LR, Field-Fote EC, Contreras-Vidal J, Noble-Haesslein LJ, Rodreick M, Shields RK, Sofroniew M, Wudlick R, Zanca JM; SCI 2020 Working Group. Meeting Proceedings for SCI 2020: Launching a Decade of Disruption in Spinal Cord Injury Research. *J Neurotrauma.* 2021 May 1;38(9):1251-66.