Review Article

# **Spinal Cord Stimulation for Poststroke Hemiparesis:** A Scoping Review

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**Importance:** Spinal cord stimulation (SCS) is a neuromodulation technique that can improve paresis in individuals with spinal cord injury. SCS is emerging as a technique that can address upper and lower limb hemiparesis. Little is understood about its effectiveness with the poststroke population.

**Objective:** To summarize the evidence for SCS after stroke and any changes in upper extremity and lower extremity motor function.

**Data Sources:** PubMed, Web of Science, Embase, and CINAHL. The reviewers used hand searches and reference searches of retrieved articles. There were no limitations regarding publication year.

**Study Selection and Data Collection:** This review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist. The inclusion and exclusion criteria included a broad range of study characteristics. Studies were excluded if the intervention did not meet the definition of SCS intervention, used only animals or healthy participants, did not address upper or lower limb motor function, or examined neurological conditions other than stroke.

**Findings:** Fourteen articles met the criteria for this review. Seven studies found a significant improvement in motor function in groups receiving SCS.

**Conclusions and Relevance:** Results indicate that SCS may provide an alternative means to improve motor function in the poststroke population.

**Plain-Language Summary:** The results of this study show that spinal cord stimulation may provide an alternative way to improve motor function after stroke. Previous neuromodulation methods have targeted the impaired supraspinal circuitry after stroke. Although downregulated, spinal cord circuitry is largely intact and offers new possibilities for motor recovery.

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More than 795,000 people in the United States have a stroke every year (Tsao et al., 2023), with many strokes leading to long-term upper limb disability. Upper extremity hemiparesis is one of the largest contributing factors to the loss of functional independence in activities of daily living (ADLs) among individuals who have survived a stroke (Mercier et al., 2001). Occupational therapy rehabilitation often focuses on compensatory approaches to improve independence in ADLs to facilitate discharge to the home environment.

Advancements in recent years have allowed for an improved understanding of the neurological mechanisms underlying motor deficits, resulting in new restorative treatment approaches to neurorehabilitation with stroke patients (Pomeroy et al., 2011). Studies using restorative approaches focus on targeting supraspinal circuitry to promote functional recovery from poststroke hemiparesis. Current rehabilitation practices to increase cortical plasticity include constraint-induced movement therapy, mirror therapy, robot-assisted training, virtual reality training, transcranial magnetic stimulation, and transcranial direct current stimulation (Ang et al., 2012, 2015; August et al., 2006; Michielsen et al., 2011; Nair et al., 2011; Schaechter et al., 2002; Straudi et al., 2016; Su & Xu, 2020).

Recent literature has shown that disturbance to the corticospinal tract (CST) leads to disrupted signaling and abnormal activation of spinal motor neurons downstream of the lesion, which contributes significantly to motor impairments (Urbin et al., 2021). Sterr et al. (2010) found that structural damage to the CST, but not infarct volume, was the major predictor of motor function. Likewise, Carter et al. (2012) found a significant correlation between the extent of CST damage and the functional capacity of the paretic limb. Increased CST damage was significantly and negatively correlated with performance on the Action Research Arm Test (ARAT), grip strength, 9-Hole Peg Test, upper extremity range of motion (ROM), FIM™ Walking subsection, and Wolf Motor Function Test (WMFT).

A stroke results in the irreversible death of neurons and cortical tissue. However, evidence indicates that spinal circuitry is less affected at the cellular level poststroke (McComas et al., 1971, 1973). Bachmann et al. (2014) examined the cortical areas and spinal circuitry of stroke-induced rodents and found that axonal sprouting in the corticospinal and reticulospinal pathways occurred during the recovery period, suggesting that spinal circuitry plays a role in functional recovery after a stroke. This was reinforced by the findings of another study using stroke-induced rodents: Kaiser et al. (2019) demonstrated that corticospinal sprouting in the spinal cord may be an avenue to improve plasticity and poststroke motor recovery. One intervention technique to induce plasticity in the CST is electrical stimulation of the spinal cord (SCS). There is a growing indication that SCS is a potential tool to improve neuromodulation as well as sensorimotor function among individuals with spinal cord injury (Lin et al., 2022; Lu et al., 2016). The various types of SCS are described in the next section.

## Types of SCS

Various types of SCS have been studied in individuals who have survived spinal cord injury, including epidural SCS and transcutaneous SCS (tSCS). tSCS consists of both transcutaneous electrical SCS (TESS) and transcutaneous spinal direct current stimulation (tsDCS). Both terms are used interchangeably, and in this review we use the original study authors' terminology. Epidural SCS is characterized by surgical implantation of electrodes into the epidural space to stimulate the dorsal aspects of the spinal cord (Darrow et al., 2019; Wagner et al., 2018). tSCS differs from epidural SCS because the electrodes are placed over the skin and deliver the current through the skin to target the spinal cord region. The cathode electrode is placed at the desired spinal cord segment or level, and the anode is placed in variable locations depending on the specific target of the stimulation (Benavides et al., 2020; Rehman et al., 2023).

tSCS has demonstrated positive results with individuals with spinal cord injury. A systematic review by Megía García et al. (2020) showed that TESS improved motor performance and function in 55 participants over 13 studies. The review found improved electromyography (EMG) activity in the upper and lower limbs, decreased time to complete the 10 Meter Walk Test (10MWT), and improved capacity to open and close the hand. McHugh et al. (2021) completed a systematic review analyzing epidural SCS in which 24 participants in 18 studies saw a net improvement in EMG activity, stepping ability, and muscle force. In addition to studies noting improvements among individuals with spinal cord injury, SCS is beginning to emerge in stroke rehabilitation research (Awosika et al., 2020; Bogacheva et al., 2023; Chua et al., 2023; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Moon et al., 2021; Moshonkina et al., 2022; Nakamura & Tsubokawa, 1985; Paget-Blanc et al., 2019; Picelli et al., 2015, 2018, 2019; Powell et al., 2023; Wang et al., 1998, 2000).

## SCS

Several proposed neurophysiological mechanisms aid in understanding SCS's influence on neuronal pathways; however, the exact mechanism remains unclear. Benavides et al. (2020) found that TESS affected afferent fiber neurons in the targeted segments of the spinal cord and dorsal horn. These large sensory afferents in the dorsal column convey excitatory inputs to motor neurons in the spinal cord. Other potential mechanisms of SCS include increasing alpha motor neuron excitability and postsynaptic inhibition and improving sensory gating mechanisms (Pirondini et al., 2022). Behavioral interventions used concurrently with or after SCS can potentially reinforce these mechanisms to promote long-lasting plastic changes in corticospinal connectivity.

Multiple studies have examined the effects of these factors separately. However, there are currently no precise guidelines on selection of these stimulation parameters. Multiple methodological configurations, including electrode size, placement, stimulation intensity, frequency, waveform, pulse duration, and modulation frequency, can alter the impact of tSCS (Taylor et al., 2021). Zheng and Hu (2020) investigated the effect of various electrode arrangements and stimulation intensities to elicit desired proximal and distal motions in healthy participants. These joint movements were achieved either independently or synergistically. This suggests the potential for SCS to elicit functional movement patterns to assist with the completion of functional activities during therapy.

Moon et al. (2021) investigated poststroke changes in lumbar spinal circuitry. They found decreased corticospinal excitability of the tibialis anterior and medial gastrocnemius muscles in chronic stroke survivors, indicating downregulation of spinal circuitry poststroke. These authors hypothesized that decreased excitability in the spinal mechanism negatively affected lower limb motor performance. Thus, upregulation of spinal circuitry could be a treatment target for individuals poststroke.

This review summarizes the research on SCS poststroke and characterizes both behavioral and neurophysiological changes.

# Method

This scoping review followed the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR; Tricco et al., 2018). As such, institutional review board approval from Northwestern University was not required.

## Data Sources and Strategy

After consultation with a librarian, a literature search in the following electronic databases was conducted: PubMed, Web of Science, Embase, and CINAHL. The PubMed database identified medical subject headings (MeSH terms) to maximize results. Search terms were grouped together using "OR" to yield a broad list of possible articles (Table A.1 in the Supplemental Material, available online with this article at https://research.aota.org/ajot). The authors completed a manual search of key authors to ensure the inclusion of all relevant articles.

## Eligibility Criteria

The initial search included research studies of any format and study design. Systematic reviews and citations without full-text availability were later excluded. The search had no year restrictions. We included articles that assessed SCS per the previous definition. To meet the definition of appropriate stimulation, the stimulation had to be delivered to the spinal cord (either transcutaneously or epidurally). Inclusion criteria were as follows: SCS with the poststroke population experiencing hemiparesis and other residual motor deficits, poststroke participants at any phase of rehabilitation, and availability in the English language. The exclusion criteria were as follows: did not meet the definition of an SCS intervention, article classified as a review or protocol, inclusion of only healthy participants, use of an animal model, interventions not targeting upper and lower limb motor function, no motor outcome or no lab motor measures (i.e., EMG, force), and study focused on any neurological condition other than stroke.

## Selection Process

Figure 1 depicts the article selection process based on the PRISMA-ScR guidelines (Tricco et al., 2018). The initial search yielded 1,962 articles. After removing duplicates and articles without titles or authors, 1,602 articles remained. Two reviewers (Jonathan R. Allen and Swathi R. Karri) performed an initial screening of titles and abstracts, considering the eligibility criteria. The 1,602 articles were ordered alphabetically by title, and each reviewer screened one half of them. After this initial screening, 47 articles remained for full-text screening. Each reviewer was assigned half of the remaining articles, and they both reviewed each final list. When a disagreement between the two reviewers occurred, the senior author (Mary Ellen Stoykov) was brought into the discussion until a consensus was reached. There was one concern during the full-text screening process: A single study was presumed a duplicate of a study that met the inclusion criteria. After discussion, the three authors reached a consensus that the article was not a duplicate because of the difference in the presented data.

Reasons for article exclusion during full-text screening included peripheral nerve stimulation only, conference abstract only, and literature review. Of the 47 full-text articles, 14 articles met the criteria for the review.

## Data Items and Data Extraction Process

A standardized charting form was developed to capture the following descriptive data: study details (author, year, type of study), design, objective, participants, chronicity of injury, intervention, types of stimulation, parameters of stimulation, outcomes, *International Classification of Functioning, Disability and Health* (*ICF*; World Health Organization, 2001) level of outcomes, and results. The PICO (Patient Problem or Population, Intervention, Comparison or Control, and Outcome) framework was used to capture study details.

# Results

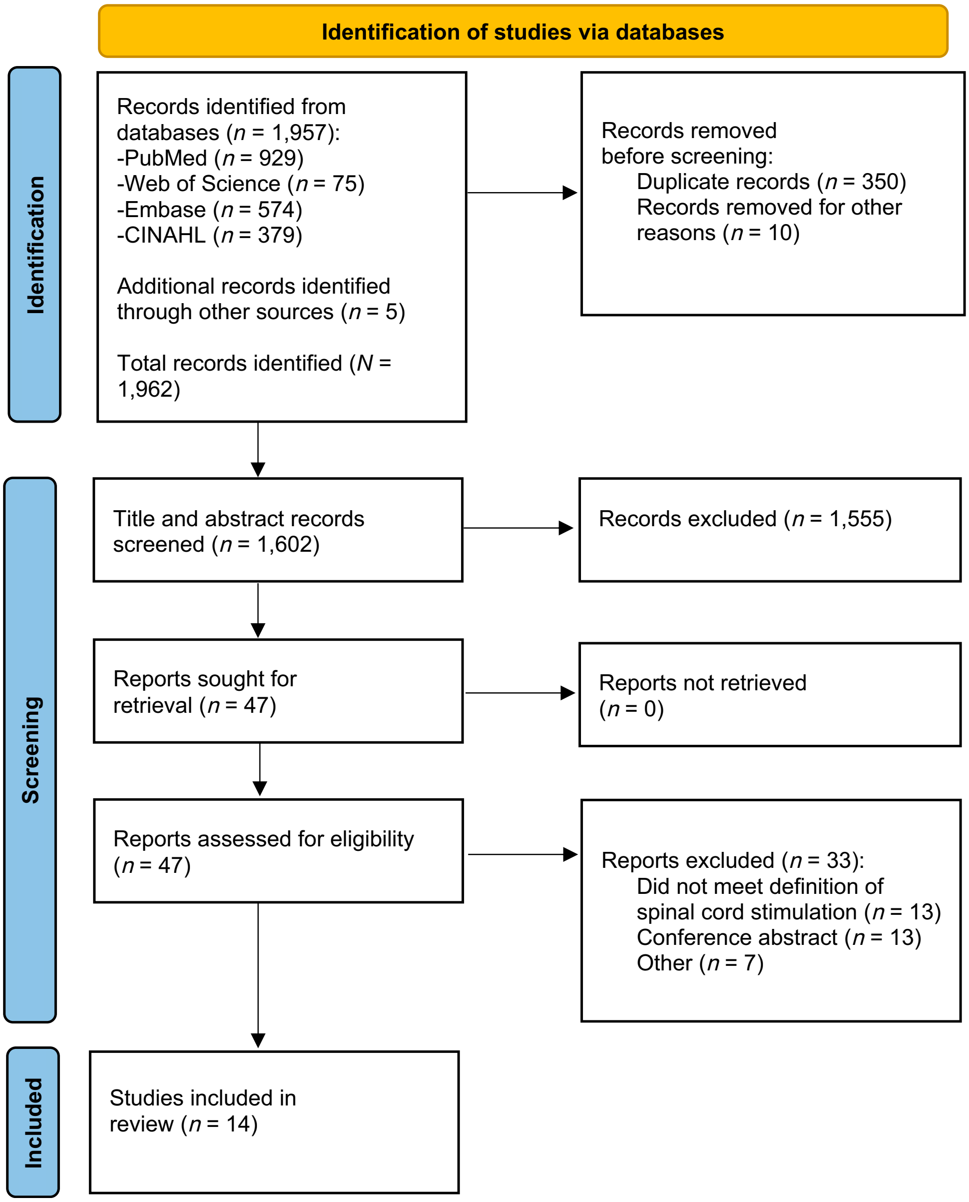
## Description of Studies

The articles in this review encompass various study designs, including case studies, prospective studies, crossover studies, and randomized controlled trials. Blinding protocols varied among studies and included 2 double-blind, 3 single-blind, and 9 open-label studies. Participants' stroke chronicity varied; 10 studies included participants more than 6 mo poststroke (chronic). Four studies included a range of chronicity. Three studies included participants who ranged from less than 6 mo poststroke (subacute) to more than 6 mo poststroke (i.e., chronic; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Moshonkina et al., 2022), and 1 study involved participants who ranged from 1 wk poststroke (acute) to more than 6 mo poststroke (Bogacheva et al., 2023). Studies varied in duration from 1 day to 6 mo, and the total number of sessions ranged from 1 to 50. All selected studies performed a baseline and postintervention test, and 7 included a follow-up evaluation. Follow-up evaluations ranged from 2 wk to 40 mo. A detailed summary of the study characteristics is provided in Table A.2 in the Supplemental Material.

## Training Interventions

The 14 studies included four types of motor training. Interventions used robot-assisted gait training ($n = 3$; Picelli et al., 2015, 2018, 2019), backward locomotor treadmill training ($n = 1$; Awosika et al., 2020), gait and ambulation training ($n = 2$; Chua et al., 2023; Moshonkina et al., 2022), and no training ($n = 8$; Bogacheva et al., 2023; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Nakamura & Tsubokawa,

**Figure 1. Flow of articles through the scoping review.**



*Note.* Figure format from "PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation," by A. C. Tricco, E. Lillie, W. Zarin, K. K. O'Brien, H. Colquhoun, D. Levac, . . . Straus, S. E., 2018, *Annals of Internal Medicine, 169,* 467–473. https://doi.org/10.7326/M18-0850.

1985; Paget-Blanc et al., 2019; Powell et al., 2023; Wang et al., 1998, 2000). Treatment protocols differed across studies. Overall, the total number of minutes of motor training intervention ranged from 0 to 40 per session across the 14 studies. A detailed description of the stimulation characteristics is provided in Table A.2.

## Outcome Measures Categorized According to the *ICF*

A total of 17 primary or secondary outcome measures were identified. Ten outcome measures analyzed the *ICF* Body Function domain and 7 analyzed the *ICF* Activities and Participation domain. The most common body functions and structure domain assessment tools were EMG recordings, the Fugl-Meyer Upper Extremity (FMUE; Fugl-Meyer et al., 1975), biomechanical parameters of gait, and the Motricity Index (Demeurisse et al., 1980). The most common activity domain assessment tools were the 6 Minute Walk Test (6MWT; Eng et al., 2004), 10MWT (Severinsen et al., 2011), WMFT (Wolf et al., 2001), and ARAT (Lyle, 1981). The behavioral and neurophysiological outcome measures are presented in Tables A.3 and A.4, respectively.

## Stimulation Methods

Three different subtypes of SCS were included in this review: epidural SCS, TESS, and tsDCS. Five studies used epidural electrical stimulation (Chua et al., 2023; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Nakamura & Tsubokawa, 1985; Powell et al., 2023), 4 used TESS (Bogacheva et al., 2023; Moshonkina et al., 2022; Wang et al., 1998, 2000), and

5 used tsDCS (Awosika et al., 2020; Paget-Blanc et al., 2019; Picelli et al., 2015, 2019, 2018). Specific stimulation protocols and parameters varied depending on the intended treatment target. Details on each stimulation protocol and its respective parameters are included in Table A.5 in the Supplemental Material.

Electrode placement varied depending on the intended treatment target: cervical level (C3–C7), thoracic level (T10–T12), and lumbar–sacral level (L1–S3). Studies targeting the upper limbs typically used cervical-level electrode placement, whereas studies targeting the lower limbs typically used thoracic- or lumbar–sacral-level placement.

The timing of stimulation can be categorized by its duration and whether it was used in training or assessment (concurrent with rehabilitation, before rehabilitation, concurrent with outcome measure administration). The duration of electrical stimulation ranged from 20 min to 14 hr/day. One study used stimulation before outcome measure testing (Paget-Blanc et al., 2019), and the remaining 13 studies used stimulation concurrent with rehabilitation training or practice of outcome measures. Finally, 4 studies also used stimulation concurrent with outcome measure testing (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Nakamura & Tsubokawa, 1985; Powell et al., 2023).

## Stimulation Interventions

The 14 studies had three groupings of neurophysiological interventions. The first group consisted of purely SCS, including epidural SCS, TESS, and tsDCSt ($n$ = 10; Awosika et al., 2020; Bogacheva et al., 2023; Chua et al., 2023; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Moshonkina et al., 2022; Nakamura & Tsubokawa, 1985; Powell et al., 2023; Wang et al., 1998, 2000). The second group consisted of SCS with transcranial direct current stimulation ($n$ = 3; Picelli et al., 2015, 2018, 2019). The final group consisted of SCS paired with peripheral nerve stimulation ($n$ = 1; Paget-Blanc et al., 2019). The stimulation protocols varied across studies. Overall, the total length of stimulation per session ranged from 20 min to 12–14 hr a day. Treatment ranged from a single day to 40 mo. A detailed description of the stimulation characteristics is provided in Table A.5.

## Study Outcomes

Of the 14 studies included in this review, 12 reported significant improvements in at least one neurophysiological or behavioral outcome (Awosika et al., 2020; Bogacheva et al., 2023; Chua et al., 2023; Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Moshonkina et al., 2022; Paget-Blanc et al., 2019; Picelli et al., 2015, 2018; Powell et al., 2023; Wang et al., 1998, 2000). *Significant improvement* can be defined as statistically significant improvement from pretest to posttest or from precrossover to postcrossover or defined as clinically significant by the authors. A detailed summary of the outcomes of the included studies is included in Tables A.3 and A.4.

## Behavioral Outcomes

### Upper Limb Studies

Of the 2 studies that analyzed the upper limb, 1 reported significant improvement in at least one behavioral outcome from pre- to postintervention (Paget-Blanc et al., 2019). In both studies that examined the FMUE (Paget-Blanc et al., 2019; Powell et al., 2023), 7 of the 19 participants had significant improvements. Paget-Blanc et al. (2019) used the WMFT, and all their participants ($n$ = 16) significantly improved at 2- and 5-wk follow-ups. Powell et al. (2023) had both participants complete behavioral outcomes with SCS and sham SCS. With sham SCS, a significant decrease in ARAT scores was noticed (Powell et al., 2023).

### Lower Limb Studies

Nine studies analyzed the effect of SCS on behavioral outcomes of the lower limb (Awosika et al., 2020; Bogacheva et al., 2023; Chua et al., 2023; Moshonkina et al., 2022; Picelli et al., 2015, 2018, 2019; Wang et al., 1998, 2000). Four of the 9 studies reported significant improvement in at least one behavioral outcome from pre- to postintervention (Awosika et al., 2020; Moshonkina et al., 2022; Picelli et al., 2018, 2019). Two studies reported significant improvements in the groups receiving SCS compared with those receiving sham SCS (Picelli et al., 2015, 2018). One study found significant improvements in the SCS group pre- and postintervention, but there was no significant difference when compared with the control group (Moshonkina et al., 2022). One study reported significant improvement pre- to postintervention in the group receiving SCS (Awosika et al., 2020). Four of 6 studies had significant pre- to postintervention improvement on the 6MWT (Awosika et al., 2020; Moshonkina et al., 2022; Picelli et al., 2018, 2019). Two studies had improvements on the 10MWT (Awosika et al., 2020; Moshonkina et al., 2022). Four studies examined muscle tone in the lower extremities, and 1 found clinically significant changes in muscle tone (Chua et al., 2023). Finally, 3 of 7 studies found a significant improvement in various gait parameters (Moshonkina et al., 2022; Picelli et al., 2015, 2018). (See Table A.4 for details.)

### Upper and Lower Limb Studies

Three studies examined the effect of SCS on behavioral outcomes in both the upper and the lower limbs. Two studies described significant improvement on at least one behavioral outcome (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989). Both of these studies examined muscle tone and gait parameters. Of the 24 participants across both studies, 16 showed significant improvements. Significant improvements were seen on Albert's Motor Scale, which is used to assess both upper and lower limb movements, for 22 of the 24 participants (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989). Nakamura and Tsubokawa (1985) noted a reduction in spasticity in all three case studies. In one of the three cases, there was an increase in elbow extension ROM (Nakamura & Tsubokawa, 1985).

### Neurophysiological Outcome Measures

Five studies incorporated neurophysiological outcome measures, including EMG recordings (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Nakamura & Tsubokawa, 1985; Wang et al., 1998, 2000).

Four studies analyzed lower limb EMG recordings (Cioni, Meglio, Prezioso, et al., 1989; Nakamura & Tsubokawa, 1985; Wang et al., 1998, 2000), and 1 study analyzed upper limb EMG recordings (Cioni, Meglio, & Zamponi, 1989). The upper limb EMG recordings examined the deltoid, triceps brachii, biceps brachii, wrist flexors, and wrist extensors. Eight of 11 participants had increased agonist–antagonist coordination, resulting in less synergic coactivation and an overall improvement in the EMG patterns of all five muscles (Cioni, Meglio, & Zamponi, 1989). Cioni, Meglio, Prezioso, et al. (1989) examined EMG recordings of the quadriceps, hamstrings, adductors, tibialis anterior, and triceps surae (consisting of the gastrocnemius, soleus, and plantaris muscles). Their results indicated increased agonist–antagonist coordination, resulting in decreased synergistic coactivation during free gait. Wang et al. (1998, 2000) analyzed EMG recordings in the tibialis anterior, triceps surae, quadriceps, and hamstring muscles after five 45-min sessions of TESS. Both studies found no significant differences in EMG activity posttreatment.

## Discussion

The results of this scoping review indicate that SCS may provide an alternative means of improving motor function. Three studies found significant differences in behavioral outcomes in groups receiving SCS compared with control groups (Paget-Blanc et al., 2019; Picelli et al., 2015, 2018). Four studies (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Moshonkina et al., 2022; Powell et al., 2023) found within-group improvement from pre- to postintervention favoring the SCS group. Two studies found improvements in neurophysiological outcomes (Cioni, Meglio, Prezioso et al., 1989; Cioni, Meglio, Zamponi, 1989). One study found a significant increase in behavioral outcomes in both SCS and sham SCS groups (Awosika et al., 2020). A decrease in behavioral outcome measures in the upper limb was observed when participants received no stimulation or sham SCS (Powell et al., 2023). None of the studies examining the lower limb tested behavioral outcome measures during no stimulation or sham SCS.

This review identifies considerable obstacles to further examination of the current literature, including the various types of SCS and associated risks; the lack of specific guidelines, resulting in large variability in stimulation parameters; the substantial variability in dosage of SCS; and the lack of therapeutic interventions implemented with SCS. Well-designed between-groups studies are required to determine whether SCS has positive benefits compared with traditional rehabilitation techniques.

## Stimulation Parameters and Protocols

Stimulation protocols in the included studies varied regarding invasiveness of stimulation, length of stimulation, and stimulation strength. The electrodes used during stimulation were implanted epidurally or delivered current transcutaneously through the skin. The length of stimulation ranged from 20 min to 12 to 14 hr/day. The stimulation ranged from 2.5 mA to 60 mA. Only 6 of the 14 studies paired activity-based rehabilitation with SCS and analyzed its impact on motor performance (Awosika et al., 2020; Chua et al., 2023; Moshonkina et al., 2022; Picelli et al., 2015, 2018, 2019). Four of the 6 studies that paired SCS with rehabilitation intervention saw significant motor improvement from preintervention to postintervention (Awosika et al., 2020; Moshonkina et al., 2022; Picelli et al., 2015, 2018).

## Limitations

SCS is an emerging intervention technique for post-stroke recovery. We sought to incorporate an extensive breadth of current research in this review. Therefore, inclusion and exclusion criteria were determined to include a broad range of study characteristics. The studies included in this review had large variations in study design, including pilot, feasibility, or case studies that yielded small sample sizes and those that included no control group.

Many of the studies did not incorporate any activity-based rehabilitation into the treatment. Future studies would greatly benefit from input from scientists with occupational therapy or physical therapy backgrounds. In addition, stimulation parameters varied across studies, and there are no specific guidelines for determining the optimal stimulation parameters at this time.

Finally, the review is limited by publication bias. Three studies did not include statistical analysis to determine significance from pre- to postintervention, instead relying on descriptive significance (Cioni, Meglio, Prezioso, et al., 1989; Cioni, Meglio, & Zamponi, 1989; Nakamura & Tsubokawa, 1985). Other limitations include that the mechanism of SCS is poorly understood, and none of the studies categorized responders and nonresponders.

## Implications for Occupational Therapy Practice

Compensatory methods that enhance daily activities have long been part of occupational therapy practice. However, developments in neuroscience have promoted new treatment approaches focusing on reducing impairment and restoring movement to its prestroke capacity (Pomeroy et al., 2011). Occupational therapy practitioners have an ethical duty to provide client-centered care to achieve meaningful outcomes and noteworthy improvements in daily function (Doucet, 2012). Stroke survivors often grieve over decreased motor function in the hemiplegic extremity and focus therapeutic goals on recovering that function (Wenzel et al., 2021). Clinicians must recognize clients' powerful desire to improve arm and leg abilities in facilitating neuroplastic changes in the supraspinal areas and improving limb function (Stoykov & Madhavan, 2015; Thieme et al., 2018). Alternatively, SCS provides the opportunity to induce neuroplastic changes in the spinal areas with subsequent recovery in motor function.

This systematic review has the following implications for occupational therapy practice:

- SCS may assist with poststroke recovery from both upper and lower extremity hemiparesis. The applicability to individuals with varying levels of impairment and various stages of recovery makes SCS practical for stroke survivors with residual hemiparesis.
- The ability to complete SCS as a preparatory activity or concurrent with activity-based rehabilitation offers versatile implementation in a therapeutic session.
- No adverse events were reported in the studies analyzed in this review, and participants reported tolerating the stimulation, which speaks to the overall safety of the technique.

## Conclusion

This systematic review summarizes the current evidence and limitations of SCS. SCS may prove to be a new remedial approach to stroke rehabilitation. The review further highlights the need for consistent protocols, parameters, outcome measures, and larger sample sizes. This review calls attention to the lack of paired activity-based rehabilitation with SCS and the lack of studies using a control group that receives a traditional rehabilitation approach. Future studies could identify the most optimal stimulation protocols and parameters. Finally, the number of published studies aimed at targeting the upper limb is small in comparison with other SCS studies targeting other neurological conditions (such as spinal cord injury).

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