

Trans-Spinal Direct Current Stimulation For Enhancing Motor Function After Anterior Cervical Discectomy And Fusion: A Narrative Review

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ABSTRACT:

Purpose of review: Trans-spinal direct current stimulation (tsDCS) has attracted growing interest as a potential neuromodulatory intervention for spinal cord injuries, especially in postoperative rehabilitation. Recently, its role in enhancing motor recovery following spinal surgeries—particularly anterior cervical discectomy and fusion (ACDF)—has gained significant attention

Methods: comprehensive search of Science Direct, PubMed, and Google Scholar was conducted using keywords such as neuromodulation, trans spinal direct current stimulation, anterior cervical discectomy and fusion, motor improvement. Articles published from February 2011 to, December 2024 were included, and only English-language studies were reviewed. Unpublished manuscripts, conference abstracts, and studies not involving larger scientific investigations were excluded.

Results: The evidence suggests that trans-spinal direct current stimulation (tsDCS), when integrated with conventional rehabilitation approaches, may enhance motor function in patients following anterior cervical discectomy and fusion (ACDF). Nonetheless, current findings are preliminary, and further large-scale, methodologically robust studies are required to validate these outcomes and develop standardized clinical protocols.

Conclusion: Current evidence supports the use of trans-spinal direct current stimulation (tsDCS) as a promising neuromodulatory approach that may serve as an adjunct to enhance motor recovery following spinal surgeries, particularly anterior cervical discectomy and fusion (ACDF). However, further high-quality clinical trials are necessary to confirm its therapeutic efficacy and elucidate the underlying neurophysiological mechanisms.

Key words: Anterior Cervical Discectomy and Fusion (ACDF), Motor Function Improvement, Neuromodulation, Trans-spinal Direct Current Stimulation (tsDCS).

1-INTRODUCTION:

Anterior cervical discectomy and fusion (ACDF) has become increasingly prevalent over the past decade. It is primarily indicated for patients with symptomatic cervical stenosis or disc herniation, which may result in radiculopathy or myelopathy. Patients with cervical radiculopathy and/or myelopathy commonly exhibit clinical manifestations including numbness, pain, spasticity, hyperreflexia, and muscle weakness (Kreitz, et al.,2018).

Pain relief and enhancement of motor function are expected outcomes following anterior cervical discectomy and fusion (ACDF). In patients with significant motor deficits, the duration of preoperative motor weakness is an independent predictor of postoperative motor recovery (Ronald, et al., 2018). Additionally, the severity of motor impairment prior to surgery plays a critical role in determining both the rate and extent of functional improvement after ACDF. (Aditya, et al.,2019).

While cervical spine surgery is effective in alleviating cervical nerve root pain, its impact on neck function remains uncertain (Tederko, et al., 2019). Cervical fusion during the early postoperative phase results in

decreased range of motion, pain, and muscle weakness. Nonetheless, atrophy and deconditioning of the cervical musculature tend to persist over time, as spontaneous recovery of muscle function is limited (Cheng, et al., 2016).

A structured postoperative rehabilitation program incorporating endurance exercises, isometric strengthening, stretching, functional training for the neck and upper limbs, and aerobic activity is recommended to enhance recovery from cervical spine dysfunction and neuropathic symptoms following surgery. Compared to standard care, the combination of therapeutic exercise and a cognitive-behavioral approach has been shown to significantly reduce neck disability and pain intensity, while improving patient satisfaction and reducing anxiety levels after surgery (Badran, et al., 2018)

Trans-spinal direct current stimulation (tsDCS) is a novel, non-invasive neuromodulation approach that has shown potential in enhancing motor function in both healthy individuals and those with corticospinal tract impairments, such as stroke or spinal cord injury. The mechanism of tsDCS is thought to involve modulation of spinal-level processes, including motoneuron excitability, spinal reflex pathways, and sensorimotor integration (Hawkins et al., 2022).

Neuromodulation methods like trans-spinal direct current stimulation (tsDCS) have been shown to promote neuroplasticity by increasing synaptic efficiency and regulating spinal reflex activity. Trans-spinal direct current stimulation provides valuable understanding of spinal control mechanisms, especially in relation to motor learning and the functional reorganization that occurs after injury to central motor regions and pathways (Kamali et al., 2021).

Evidence indicates that spinal stimulation not only enhances motor output but also modulates motor unit recruitment, thereby improving neuromuscular function in both healthy individuals and those with central nervous system (CNS) disorders (Pierantoni et al., 2024), including those with ongoing motor impairments after undergoing anterior cervical discectomy and fusion (ACDF). Trans-spinal direct current stimulation (tsDCS) has the capacity to produce lasting alterations in spinal cord excitability, promoting neuroplasticity within spinal circuits and contributing to improved motor function (Yamaguchi et al., 2020).

2- OVERVIEW ON TRANS- SPINAL DIRECT CURRENT STIMULATION:

Trans-spinal direct current stimulation (tsDCS) represents an innovative, non-invasive technique aimed at regulating the functional activity of spinal cord networks. It involves the transcutaneous application of direct current via rubber electrodes placed on the skin, typically with conductive gel or saline-soaked sponges. In standard protocols, the active electrode is positioned over the spinous process or intervertebral segment at the cervical, thoracic, or lumbar level, while the reference electrode is commonly placed on the shoulder either over the deltoid or supra scapular region. However, research has shown that variations in electrode placement specifically the positioning of the anode and cathode can result in differing neurophysiological effects in healthy individuals (Kuk et al., 2018).

Trans-spinal direct current stimulation (tsDCS) delivers a steady, painless, safe, and effective electrical current. This form of stimulation can modulate both cortical and subcortical transmission within the spinal cord, potentially leading to functional recovery following spinal cord injuries, the physiological effects of direct current stimulation are influenced by factors such as the targeted neural structures, synaptic connections, and the polarity of the electrodes whether anodal or cathodal (Ahmed et al., 2011).

Researches have shown that trans-spinal direct current stimulation applied to resting membrane potentials can facilitate both long-term potentiation (LTP) and long-term depression (LTD), mechanisms crucial for synaptic plasticity. Additionally, trans spinal direct current stimulation has been associated with alterations in glutamatergic neurotransmission, the primary excitatory signaling pathway in the central nervous system (Niérat et al., 2014).

Trans-spinal direct current stimulation (tsDCS) has shown potential as a therapeutic approach for addressing various neurological dysfunctions involving the corticospinal tract, including in the context of spinal cord injury (SCI) rehabilitation. As one of several neuromodulation techniques designed to influence nervous system activity through the application of an electric field, tsDCS employs subthreshold direct current

delivered via surface electrodes placed on the skin. Unlike most DC stimulation methods, which primarily target cortical regions, tsDCS is intended to modulate neuronal activity at specific spinal levels. Studies have demonstrated that tsDCS can influence several spinal and corticospinal mechanisms, including H-reflex excitability, presynaptic inhibition, and alterations in both somatosensory and motor evoked potentials (Stegeman, et al., 2019).

3- SAFETY OF TRANS SPINAL DIRECT CURRENT STIMULATION:

Although safety data on trans-spinal direct current stimulation (tsDCS) remain limited, no spinal-specific adverse events have been reported to date. To rule out direct neurotoxic effects, studies have assessed serum levels of neuron-specific enolase (NSE) before and immediately after tsDCS sessions, with no indication of neuronal damage. While the stimulation parameters used in tsDCS protocols are generally consistent with those employed in transcranial direct current stimulation (tDCS), the possibility of localized harmful effects such as those arising from increased current density through anatomical structures like the spinal foramina cannot be entirely excluded (Kuck et al., 2019).

Further investigations have confirmed that trans-spinal direct current stimulation (tsDCS) is safe for individuals with spinal implants. Researches have shown only minimal changes in electric field distribution and current density around implant sites, with no evidence of current accumulation or tissue damage. Although a slight increase in current density can occur near the borders of the implant, the highest recorded peak value across all implant positions and electrode configurations was approximately (1.04 A/m²), which is nearly six times lower than the estimated safety threshold for tissue damage, reported at (6.3 A/m²). These findings indicate that tsDCS does not generate unsafe current density levels in the presence of spinal implants, supporting its use in patients with spinal metal implant (van Asseldonk, et al., 2019).

4 MECHANISMS OF ACTION OF TRANS-SPINAL DIRECT CURRENT STIMULATION:

The mechanisms of action of tsDCS are currently under discussion. Some authors have shown changes due to segmental modulation on the synaptic efficacy and axonal conduction disruption⁹, at the spinal level, while others found modulation response at the brain level, suggesting that tsDCS spreads beyond spinal structures. Upper limb sensorimotor innervation arises mostly from the cervical region of the spinal cord (SC). Several clinical conditions, such as upper limb weakness, sensory deficit or pain, can be associated with cervical spinal circuitry dysfunctions (Sofia, et al., 2019). Previous studies have proposed that combining trans-spinal direct current stimulation (tsDCS) with hand training may enhance hand function in healthy individuals more effectively than either intervention alone, by promoting neuroplastic changes at both spinal and cortical levels. Recent findings have shown that this combined approach helps maintain maximum voluntary contraction (MVC), increases F-wave amplitude and persistence, and reduces cortical resting motor threshold (RMT), indicating heightened excitability of the motor pathways (Kumru et al., 2021).

Spinal stimulation alone was found to increase F-wave amplitude, while hand training by itself led to a reduction in maximum voluntary contraction (MVC), along with increases in cortical resting motor threshold (RMT) and short-interval intracortical inhibition (SICI). Notably, placing the cathodal electrodes at the C3-C4 and C6-C7 spinal segments enabled targeted stimulation of specific spinal regions, which in turn enhanced the excitability of anterior horn motoneurons, as evidenced by changes in RMT and corticospinal motor evoked potentials (cMEPs). This strategic electrode placement allowed for effective modulation of both spinal and cortical excitability, likely mediated by neuroplastic adaptations, and contributed to improved functional outcomes in hand motor performance (Luca, et al., 2024).

Trans-spinal direct current stimulation (tsDCS) has also been reported to improve voluntary ballistic activation of the ankle musculature and enhance the descending input to spinal motoneurons in healthy individuals. According to (Yamaguchi et al. 2020), this effect may result from a transient increase in corticospinal drive to the motor neurons innervating the plantar flexor muscles.

A recent study aimed to integrate computational modeling with experimental approaches to identify the optimal electrode configuration for maximizing electric field (E-field) delivery during cervical trans-spinal

direct current stimulation (tsDCS). Using a realistic human model, the study evaluated current and E-field distributions across four electrode montages. Each electrode configuration resulted in increased current density and electric field strength within the targeted region of the cervical spinal cord situated between the electrode sites. Notably, the montage with electrodes positioned over the C3 and T3 spinous processes (C3-T3) produced the highest E-field magnitude, reaching 0.50 V/m (Mariana et al., 2024).

5- CLINICAL APPLICATIONS OF TRANS-SPINAL DIRECT CURRENT STIMULATION:

Trans-spinal direct current stimulation (tsDCS) has been increasingly investigated in clinical trials for its therapeutic potential across various neurological disorders, including pain (Magnus, et al., 2020), spasticity (Maria, et al., 2022), and motor dysfunction. Although research is still ongoing, tsDCS has demonstrated promise in modulating spinal cord excitability, which may translate into clinical improvements. Additionally, its application is being explored in the management of conditions such as orthostatic tremor (Lamy, et al., 2019).

6- POSSIBLE COMPLICATIONS OF TRANS-SPINAL DIRECT CURRENT STIMULATION:

A study investigating the side effects of trans-spinal direct current stimulation (tsDCS) documented several potential adverse effects. The most frequently reported were skin redness (60.66%), burning sensations (40%), tingling (26.67%), and itching (20%). These effects typically appeared within the first minute of stimulation, lasted for 1-2 minutes, and were confined to the skin area beneath the electrodes. Additionally, some participants reported sleepiness (6.67%) and difficulty concentrating (1.67%) during certain sessions (Hongyan et al., 2023).

7- CONCLUSION:

Trans-spinal direct current stimulation (tsDCS) appears to be a promising intervention for enhancing motor function in patients following anterior cervical discectomy and fusion (ACDF). Nonetheless, additional research involving larger cohorts and longer follow-up durations is essential to validate these results and determine the long-term sustainability of the therapeutic effects.

DISCLOSURE STATEMENT:

No author has any financial interest or received any financial benefit from this research.

CONFLICT OF INTEREST:

Authors state no conflict of interest

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