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RTMS IN THE FUTURE OF SCI REHABILITATION

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Spinal cord injury (SCI) often results in long-term disability and limited meaningful neurological recovery. Current rehabilitation strategies focus on physical therapy and assistive devices. Neuromodulation techniques such as repetitive transcranial magnetic stimulation (rTMS) have emerged as promising tools to enhance neuroplasticity and functional recovery. We hereby explore the mechanisms, clinical applications, and future potential of rTMS in SCI rehabilitation. Introduction SCI disrupts neural pathways. With growing interest in neuromodulation technologies, rTMS has gained attention as a potentially transformative intervention for enhancing neuroplasticity and functional recovery. While initially developed for psychiatric and motor disorders, its application in SCI is expanding.

Mechanisms of rTMS in SCI The therapeutic potential of rTMS lies in its capacity to modulate corticospinal excitability and promote plasticity in spared neural pathways: - Cortical Excitability: High-frequency rTMS (>5 Hz) enhances excitability; low-frequency (<1 Hz) suppresses it. - Neuroplasticity: rTMS induces long-term potentiation or depression effects, supporting synaptic remodeling, potentially rebalancing disrupted motor networks. It may strengthen residual connections and promote axonal sprouting. - Spinal Circuitry Modulation: Indirect influence on spinal interneurons and residual motor pathways below the lesion and central pattern generators may improve locomotion. - Neurochemical Changes: Alters levels of brain-derived neurotrophic factor, dopamine and glutamate, key mediators of recovery, reducing secondary damage by inflammatory responses. Clinical Evidence Motor Recovery Studies demonstrate improved voluntary movement and muscle strength, particularly in incomplete SCI: -Benavides et al. (2021): High-frequency rTMS over the motor cortex enhanced hand function in chronic cervical SCI. -Kumru et al. (2016): rTMS combined with physical therapy showed greater gains in gait and lower limb strength. Sensory Improvements rTMS over motor or prefrontal cortex may enhance sensory thresholds and reduce neuropathic pain, modulating the thalamo-cortical loop and endogenous opioid release: -Nardone et al. (2017) reported improved somatosensory evoked potentials after rTMS in SCI patients. Autonomic Function - Emerging evidence suggests benefits in bladder control and cardiovascular regulation, though results remain preliminary. Future Directions - Individualized Protocols AI-driven personalization (fMRI and EEG biomarkers) may optimize frequency, location, and duration of rTMS.

Combination Therapies rTMS + Physical Therapy: Enhances cortical priming. rTMS + Exoskeletons or Robotic Gait Training: May facilitate more robust sensorimotor recovery. rTMS + Pharmacotherapy: Synergistic effects with neurotrophic agents. - Closed-Loop Systems Adaptive rTMS triggered by real-time biofeedback (EEG/EMG) could adjust stimulation dynamically. - Home-Based and Wearable rTMS Portable devices are under development, potentially enabling telerehabilitation applications. Limitations

Heterogeneity in SCI populations complicates response to rTMS (varies based on injury severity and baseline neural integrity). Optimal stimulation parameters (frequency, intensity, duration) remain unclear. Long-term effects and safety need further study Conclusion Repetitive transcranial magnetic stimulation presents promising, offering the ability to modulate neural circuits non-invasively. While still in the early stages, rTMS holds the potential to redefine recovery, with benefits in motor recovery, spasticity, pain, and autonomic function. Future research should focus on optimizing protocols, understanding long-term effects, and integrating rTMS into multimodal rehabilitation approaches.

Keywords: rTMS, SCI, rehabilitation, functional recovery

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