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Novel Therapeutic Approaches for Spinal Cord Injury: A Systematic Review

RITU RAJ[1], APARNA BARARIA[2]

ABSTRACT

Introduction: Spinal Cord Injury (SCI) results in profound motor, sensory, and autonomic impairments that limit independence and quality of life. Conventional rehabilitation approaches provide partial recovery but often fail to optimise cardiovascular health, ambulation, and psychosocial outcomes. Recent advances in exercise, neuromodulation, exoskeleton robotics, and hybrid Functional Electrical Stimulation (FES) has expanded opportunities for functional recovery.

Aim: This systematic review aimed to synthesise evidence from randomised controlled trials and related protocols investigating rehabilitation interventions in adults with acute, subacute, and chronic SCI, highlighting their efficacy across motor, cardiovascular, and quality-of-life domains.

Materials and Methods: A systematic review of Randomised Controlled Trials (RCTs) and pilot studies published between 2021 and 2024 were conducted. Databases, including PubMed and Google Scholar, were searched using terms related to SCI rehabilitation, locomotor training, FES, exoskeletons, neuromodulation, and virtual exercise. Twenty relevant studies were included, with sample sizes ranging from pilot cohorts to multi-site trials, and interventions including hybrid FES rowing, Trans-spinal Stimulation (TSS), exoskeleton-assisted walking, progressive resistance training, blood flow restriction exercise, and virtual or tele-exercise programmes.

Results: Hybrid FES interventions improved cardiovascular parameters and body composition, although neurological recovery remained limited in some trials. TSS combined with locomotor training enhanced walking independence and plasticity compared to sham. Exoskeleton training consistently improved ambulatory outcomes, especially in incomplete and subacute SCI, with metaanalysis confirming greater benefit in patients less than six months post-injury. Progressive resistance training with FES increased strength and muscle volume, while blood flow restriction promoted hypertrophy without major strength gains. Virtual and tele-exercise programmes demonstrated feasibility and improved activity levels. Behavioural care models reduced pain, depression, and improved quality of life.

Conclusion: Rehabilitation strategies combining advanced technologies such as FES, TSS, and exoskeleton robotics with conventional therapy signifi cantly enhance functional outcomes and cardiometabolic health in SCI. While feasibility is established, large-scale standardised trials are required to optimise protocols and tailor interventions to injury stage and severity.

Keywords: Exoskeleton training, Functional electrical stimulation, Rehabilitation, Transspinal stimulation

PARTICULARS OF CONTRIBUTORS:
1. Undergraduate Student, Department of Biomedical and Allied Health Sciences, Baba Farid Group of Institutions, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India.
2. Assistant Professor, Department of Biomedical and Allied Health Sciences, Baba Farid Group of Institutions, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Aparna Bararia,
Assistant Professor, Department of Biomedical and Allied Health Sciences, Baba Farid Group of Institutions, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India.
Email: aparna8482@gmail.com