Implementing Omics Technologies to Analyze Rehabilitation Strategies in Spinal Cord Injury

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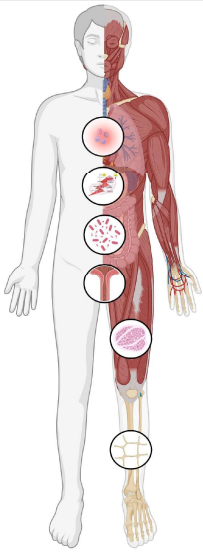
Background

Spinal cord injury (SCI) can disrupt sensory, motor, and autonomic functions, significantly affecting recovery and quality of life.[1] Despite these advancements, rehabilitation remains limited due to the complexity of neuronal regeneration and plasticity.[2] Omics-based approaches (genomics, epigenomics, metagenomics, transcriptomics, proteomics, and metabolomics) can provide insights into the molecular mechanisms, such as:

- neuroinflammation (increase in proinflammatory cytokines,
- metabolic shifts/ disorders,
- gut microbiota imbalance (increase of harmful taxa),
- urinary tract infections,
- loss of muscle mass (muscular atrophy),
- loss of bone density (osteoporosis),

influencing rehabilitation outcomes.[3]



Objectives

- Give a comprehensive overview of omics technologies used in analyzing rehabilitation interventions
- Effectiveness of different interventions in SCI rehabilitation, where omics technologies are used to assess biological changes triggered by rehabilitation strategies and assess molecular outcomes.

Methods

Three databases (Embase, Medline, Web of Science) were searched. Two reviewers independently screened, extracted data and assessed risk of bias (RoB) (National Heart Lung and Blood Institute Quality Assessment Tool).

Inclusion criteria:

- Age ≥18 years; traumatic SCI; assessed outcomes through omics; published in peer-reviewed journal

Exclusion criteria:

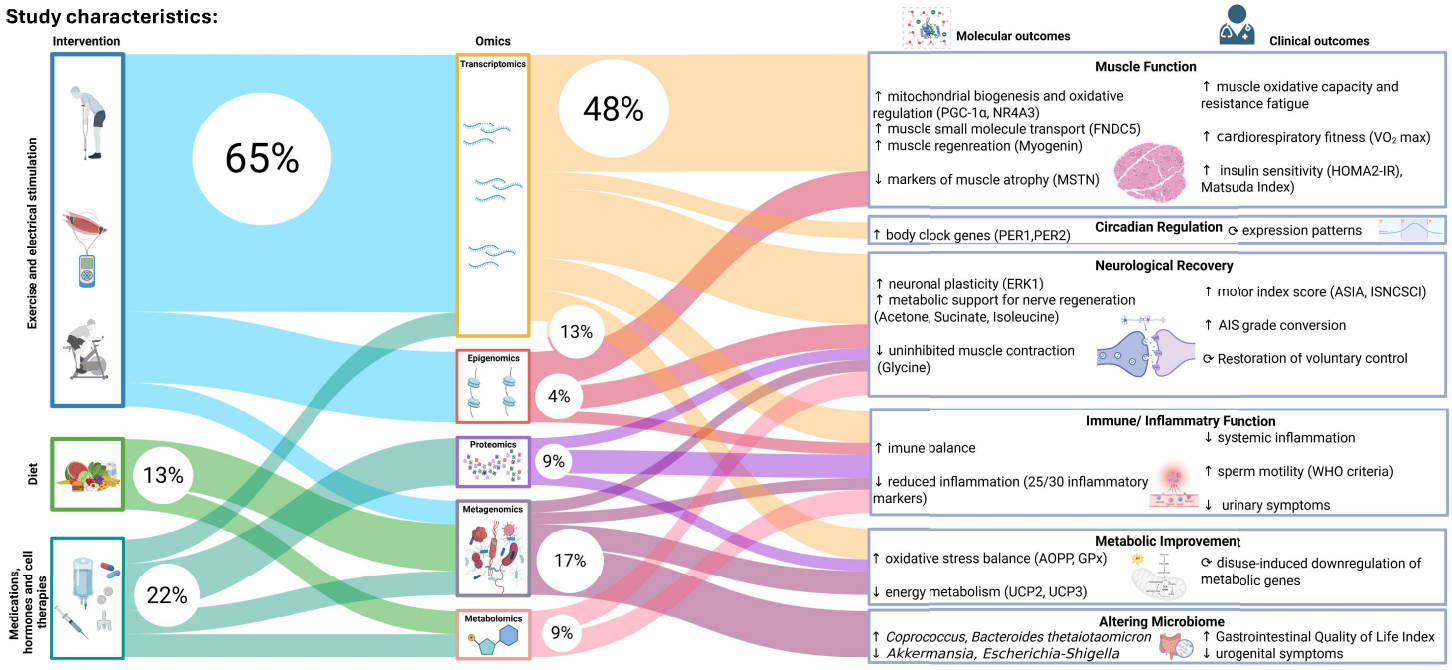
- Animal studies, reviews, commentaries, and conference abstracts

Main Results

Literature research:

6,021 references retrieved, 136 full-text articles reviewed, 23 trials included (8 RCTs, 5 non-RCTs, 10 pre-post trials); 96% moderate RoB.

Study characteristics:



Conclusion

- Omics technologies are increasingly used (2012: n = 2; 2025: n = 14)
  - Enable monitoring of biological adaptations
  - Transcriptomics & metagenomics most used
- Exercise & electrical stimulation drive muscle gene adaptation
- Microbiome shifts reduce inflammation
  - Linked to better bowel and metabolic outcomes
- Epigenomics shows lasting molecular effects
  - Suggests sustained adaptation potential
- Proteomics & metabolomics detect systemic changes
  - Hormones & cell therapies → signature proteins/metabolites
- Early molecular shifts can guide rehabilitation
  - May forecast recovery ahead of clinical signs
  - Enable real-time intervention tuning
- Current evidence is promising but limited
  - Most studies small, short, and high variability
  - Need for standardized (multi)-omics clinical trials

References: [1]Ahuja, C.S., et al., Traumatic spinal cord injury. Nature Reviews Disease Primers, 2017. 3(1): p. 17018 DOI: 10.1038/nrdp.2017.18. [2]Nagappan, P.G., H. Chen, and D.-Y. Wang, Neuroregeneration and plasticity: a review of the physiological mechanisms for achieving functional recovery postinjury. Military Medical Research, 2020. 7(1): p. 30 DOI: 10.1186/s40779-020-00259-3. [3]Martínez-Torija, M., Esteban, P. F., Santos-De-La-Mata, A., Castillo-Hermoso, M., Molina-Holgado, E., & Moreno-Luna, R. (2025). Multifaceted Pathophysiology and Secondary Complications of Chronic Spinal Cord Injury: Focus on Pressure Injury. Journal of Clinical Medicine, 14(5), 1556. https://doi.org/10.3390/jcm14051556