A Systematic Review of Translating Omics Research into Practice: Implementing Precision Rehabilitation Strategies for 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 (QoL)[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, metabolic shifts, and neurological recovery, 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.

Complications after SCI
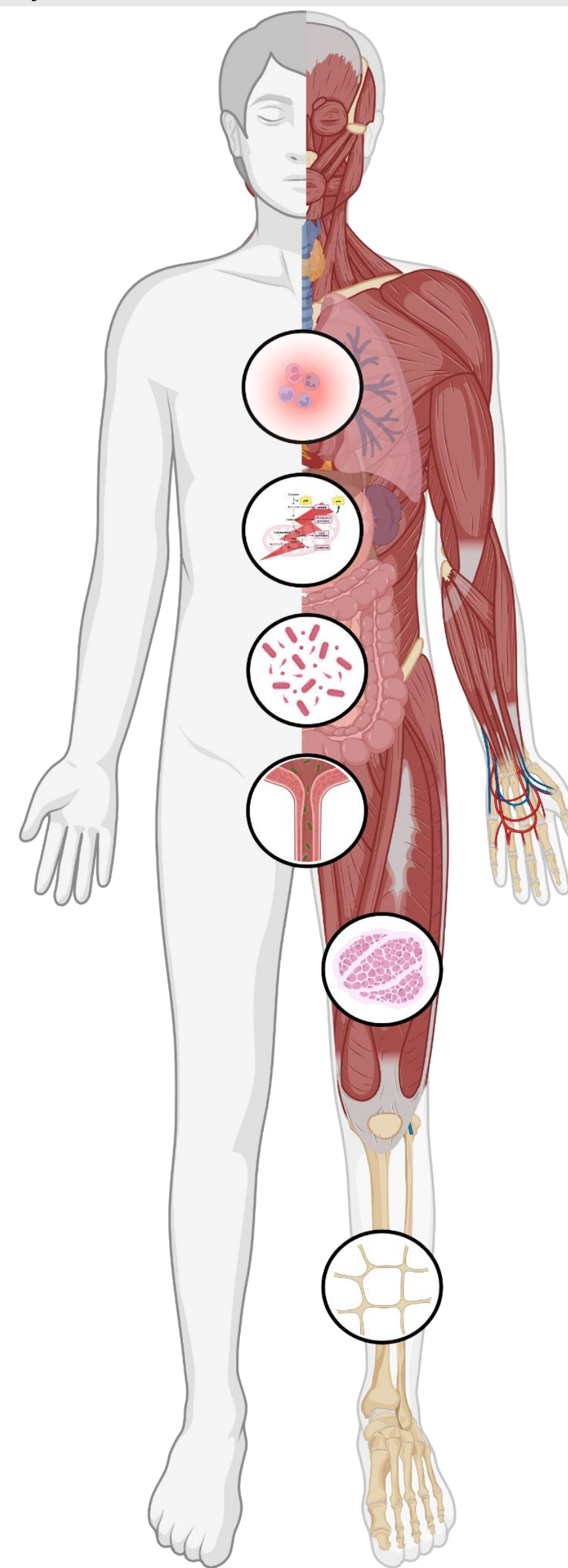
- Increase in proinflammatory cytokines.
- Metabolic disorders.
- Gut microbiome imbalance.
- Urinary tract infections.
- Loss of muscle mass.
- Loss of bone density.

Methods

Three databases (Embase, Medline [Ovid], Web of Science) were searched. The search was last conducted from inception until 27 November 2024 without language and year restrictions. The research was limited to traumatic SCI in humans. Study Articles screening, data extraction and risk of bias assessment (National Heart Lung and Blood Institute Quality Assessment Tool) were done independently by two reviewers.
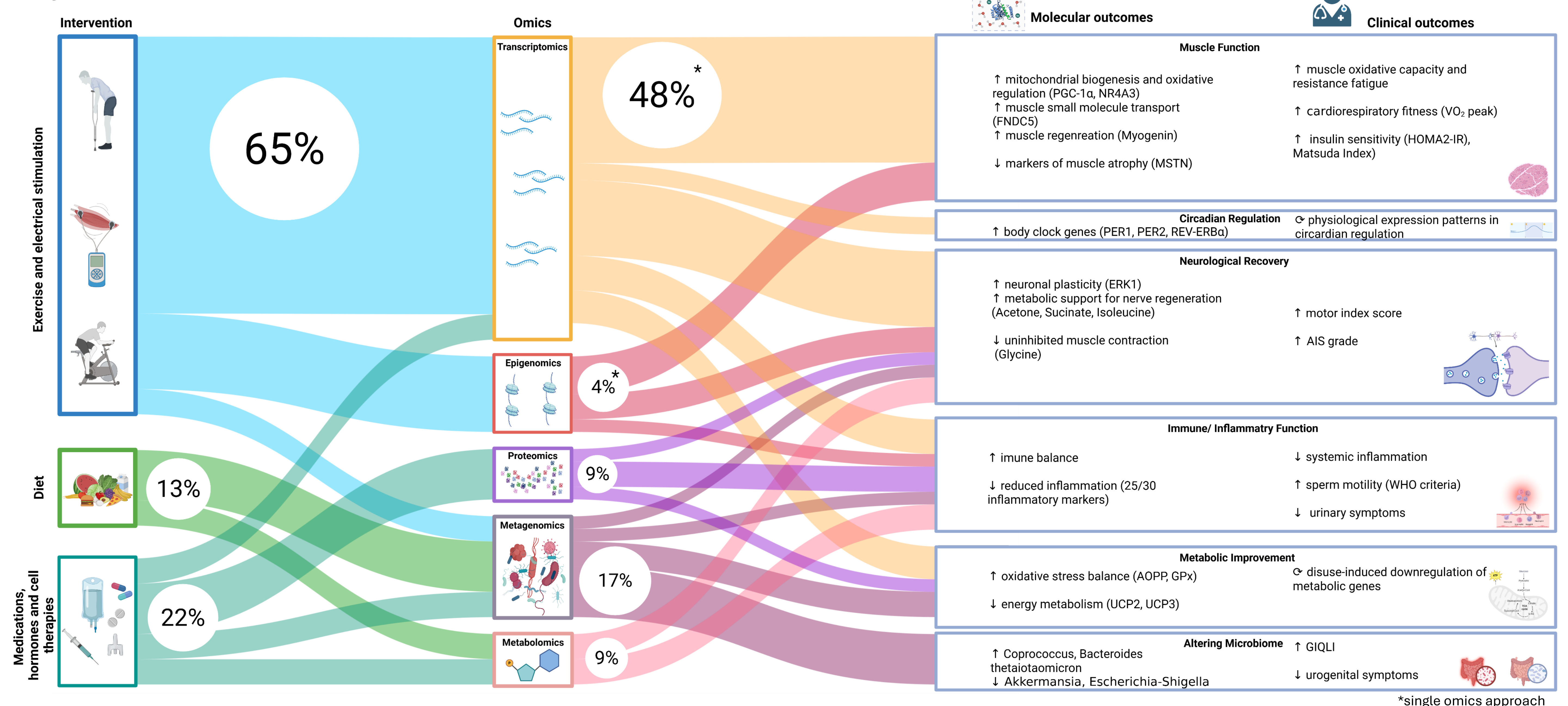
Main Results

Literature research: 6,021 references retrieved, 136 full-text articles reviewed, 23 trials included —
- 8 randomized controlled trials (RCTs)
- 5 non-RCTs
- 10 pre-post trials

Study characteristics:

Sankey diagram linking Interventions (Exercise and electrical stimulation 65%, Diet 13%, Medications, hormones and cell therapies 22%) to Omics (Transcriptomics 48%*, Epigenomics 4%*, Proteomics 9%, Metagenomics 17%, Metabolomics 9%) to Molecular and Clinical outcomes.

Molecular outcomes / Clinical outcomes

Muscle Function
- ↑ mitochondrial biogenesis and oxidative regulation (PGC-1α, NR4A3)
- ↑ muscle small molecule transport (FNDC5)
- ↑ muscle regenreation (Myogenin)
- ↓ markers of muscle atrophy (MSTN)
- ↑ muscle oxidative capacity and resistance fatigue
- ↑ cardiorespiratory fitness (VO₂ peak)
- ↑ insulin sensitivity (HOMA2-IR, Matsuda Index)

Circadian Regulation
- ↑ body clock genes (PER1, PER2, REV-ERBα)
- ↻ physiological expression patterns in circardian regulation

Neurological Recovery
- ↑ neuronal plasticity (ERK1)
- ↑ metabolic support for nerve regeneration (Acetone, Sucinate, Isoleucine)
- ↓ uninhibited muscle contraction (Glycine)
- ↑ motor index score
- ↑ AIS grade

Immune/ Inflammatry Function
- ↑ imune balance
- ↓ reduced inflammation (25/30 inflammatory markers)
- ↓ systemic inflammation
- ↑ sperm motility (WHO criteria)
- ↓ urinary symptoms

Metabolic Improvement
- ↑ oxidative stress balance (AOPP, GPx)
- ↓ energy metabolism (UCP2, UCP3)
- ↻ disuse-induced downregulation of metabolic genes

Altering Microbiome
- ↑ Coprococcus, Bacteroides thetaiotaomicron
- ↓ Akkermansia, Escherichia-Shigella
- ↑ GIQLI
- ↓ urogenital symptoms

*single omics approach

Conclusion

Omics technologies are increasingly applied in research trials, investigating molecular adaptations of rehabilitation interventions after SCI. These methods enable the early identification of molecular changes and have shown relevance in analyzing processes related to metabolism, endocrine function, and inflammation. While not yet part of clinical routine, omics approaches provide valuable insights in the rehabilitation setting and hold potential for informing the design and monitoring of future strategies

References

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