# Walking again with Epidural Spinal Stimulation: A Prisma-Guided Synthesis of Human Walking Outcomes (2020-2025)

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## Abstract

Introduction: Spinal cord injury produces profound motor deficits that remain refractory to conventional rehabilitation. In recent years, epidural electrical stimulation targeted to lumbosacral circuits has enabled standing and overground stepping from early postoperative sessions, with additional gains after task-specific rehabilitation. Building on these advances, we synthesized contemporary human evidence (2020-2025) focused specifically on walking outcomes to clarify clinically meaningful effects and practical levers for protocol standardization.

Method: Design: Systematic review compliant with PRISMA guidelines. Data sources: PubMed and Google Scholar (Jan 2020-Sep 2025). Eligibility: Original human studies of surgically implanted epidural stimulation reporting walking outcomes (walking speed, six-minute walk distance, Timed Up and Go, symmetry index, and overground ambulation). Trials, before-after studies, and case series/reports were included; animal studies, non-epidural stimulation, technical notes only, and reviews were excluded. Two reviewers screened and extracted data. Given heterogeneity, we used a structured synthesis without meta-analysis based on pre-specified clinically important differences: speed > 0.10 m/s, six-minute walk distance > 50 m, Timed Up and Go -3 s, symmetry index > 20% improvement; overground ambulation summarized as achieved vs not achieved.

Results: Eight studies met criteria (single-patient reports to a 25-patient series; total 38 participants), spanning incomplete and motor-complete injuries. Across designs, most reports showed clinically important gains in walking speed and/or six-minute walk distance; incomplete-injury cohorts frequently improved symmetry. Crucially, overground ambulation was newly achieved or clearly upgraded in several reports, including motor-complete cases. Three convergent signals emerged that likely facilitate ambulation: ventral lead placement enabling rapid distance walking within weeks; high-frequency paradigms reducing spasticity and improving inter-joint coordination; and intent-coupled adjuncts (robotic training or brain-spine interfaces) promoting naturalistic gait and task generalization (uneven terrain, stairs). Adverse events were infrequent and mostly minor. Certainty is limited by small samples, non-randomized designs, heterogeneous co-interventions, and variable outcome timing.

Discussion: Converging human evidence indicates that epidural stimulation can acutely unlock stepping and produce training-mediated gains over weeks to months. Emerging paradigms-ventral targeting, high-frequency modulation, and intention-coupled assistance-appear to broaden candidacy and improve gait quality, but require standardization across centers.

Conclusions: Epidural stimulation is associated with clinically meaningful restoration of ambulation after spinal cord injury, from incomplete to motor-complete cases. Multicenter comparative studies should standardize targets and dosing, pre-specify common walking endpoints (speed, six-minute walk distance, symmetry, overground status), and stratify by impairment level, lesion topology, and use of ventral/high-frequency approaches and intention-coupled adjuncts.