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Rehabilitation and Physical Therapy Interventions in Spinal Cord Injuries Based on the Level of Injury: A Systematic Review

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الملخص:

إصابة الحبل الشوكي هي حالة عصبية خطيرة غالباً ما تؤدي إلى ضعف وظيفي كبير، حيث تعتمد نتائج التأهيل بشكل كبير على مستوى الإصابة.

يهدف هذا الاستعراض المنهجي إلى تحليل تدخلات التأهيل والعلاج الطبيعي لدى المرضى المصابين بإصابات الحبل الشوكي وفقاً لمستوى الإصابة، بما في ذلك الفقرات العنقية والصدرية والقطنية، مع إبراز مفهوم تأهيلي تكاملي يُعرف باسم هندسة الجسد (Body Engineering).

تم إجراء بحث منهجي في قواعد البيانات الإلكترونية مثل PubMed وScopus و Web of Science وGoogle Scholar لتحديد الدراسات ذات الصلة المنشورة باللغة الإنجليزية.

تم فحص الدراسات المختارة وتحليلها وفقاً لإرشادات PRISMA.

كما تشير النتائج إلى أن إصابات الحبل الشوكي العنقية، التي غالباً ما تؤدي إلى شلل رباعي، تتطلب استراتيجيات تأهيلية معقدة ومكثفة تركز على الرعاية التنفسية، والحركة بمساعدة، ووظائف الأطراف العلوية.

بالمقابل، تُظهر الإصابات الصدرية والقطنية، المرتبطة عادة بالشلل النصفي، نتائج وظيفية أفضل نسبياً، خصوصاً في برامج تدريب المشي، والتوازن، وتقوية الأطراف السفلية.

يؤكد هذا الاستعراض أن اعتماد إطار عمل منظم ومفصل للعلاج الطبيعي، يُصاغ ضمن مفهوم هندسة الجسد، قد يعزز التعافي الوظيفي من خلال معالجة المكونات البيوميكانيكية والعصبية العضلية والوظيفية وفقاً لمستوى إصابة الحبل الشوكي.

استخدم البحث الكلمات المفتاحية التالية: "إصابة الحبل الشوكي"، "العلاج الطبيعي"، "التأهيل"، "إصابة الحبل الشوكي العنقية"، "إصابة الحبل الشوكي الصدرية"، "إصابة الحبل الشوكي القطنية"، "الشلل النصفي"، "الشلل الرباعي"، و"هندسة الجسد (Body Engineering)"

Abstract:

Spinal cord injury is a serious neurological condition that often leads to significant functional impairments, with rehabilitation outcomes highly dependent on the level of injury. This systematic review aimed to analyze rehabilitation and physical therapy interventions in patients with spinal cord injuries according to the level of injury, including the cervical, thoracic, and lumbar vertebrae, while highlighting an integrative rehabilitation concept referred to as Body Engineering.

A systematic search of electronic databases such as PubMed, Scopus, Web of Science, and Google Scholar was conducted to identify relevant studies published in English. The selected studies were screened and analyzed in accordance with PRISMA guidelines. The findings indicate that cervical spinal cord injuries, which often result in quadriplegia, require complex and intensive rehabilitation strategies focusing on respiratory care, assisted mobility, and upper limb function. In contrast, thoracic and lumbar injuries, commonly associated with paraplegia, show relatively better functional outcomes, particularly in gait training, balance, and lower limb strengthening programs. The review emphasizes that adopting a structured and individualized physical therapy framework, conceptualized as Body Engineering, may enhance functional recovery by addressing biomechanical, neuromuscular, and functional components according to the level of spinal cord injury.

The search used the following keywords in various combinations:

"Spinal Cord Injury," "Physical Therapy," "Rehabilitation," "Cervical Spinal Cord Injury," "Thoracic Spinal Cord Injury," "Lumbar Spinal Cord Injury," "Paraplegia," "Quadriplegia," and "Body Engineering."

Introduction :

Spinal cord injury (SCI) is a catastrophic neurological condition that interrupts neural pathways and results in permanent or long-term loss of motor, sensory, and autonomic functions below the level of lesion (Fawcett et al., 2007). The effects of SCI range from partial impairment to complete paralysis, and the severity of functional deficits depends on the level and completeness of the injury. Cervical injuries frequently result in quadriplegia, severely affecting both upper and lower limbs, whereas thoracic and lumbar injuries are more often associated with paraplegia, primarily impairing lower limb function and mobility (van Middendorp et al., 2011). Functional outcomes and rehabilitation goals therefore vary substantially according to the injury level (Dietz & Curt, .2006)

Rehabilitation following SCI aims to maximize functional independence, minimize secondary complications, and improve quality of life through multidisciplinary care. Physical therapy is a core component of this process, incorporating interventions such as gait training, balance exercises, strength conditioning, locomotor training, functional electrical stimulation, and task-specific practice to facilitate neuroplasticity and enhance motor recovery (Fehlings et al., 2017). Evidence from systematic reviews indicates that physical therapy interventions can significantly improve functional outcomes, including mobility, balance, and muscle strength, although the degree of benefit often depends on the level and .chronicity of the injury (van den Berg et al., 2010)

Despite the established role of conventional rehabilitation methods, there is increasing interest in developing more integrated frameworks that organize therapeutic strategies according to the specific biomechanical and functional demands imposed by different SCI levels. In this context, this review introduces the conceptual framework termed Body Engineering, which aims to tailor physical therapy interventions by integrating biomechanical principles, neuromuscular activation patterns, and functional task demands specific to cervical, thoracic, and lumbar SCI. This conceptual approach provides a structured perspective on optimizing physical therapy strategies across injury levels and may guide .more precise clinical decision-making

The objective of this systematic review is to critically examine and synthesize the existing literature on rehabilitation and physical therapy interventions in individuals with spinal cord injuries, with a particular focus on differential functional outcomes based on level of injury and the potential application of Body Engineering principles in clinical practice.

Methods:

Study Design:

This study was conducted as a systematic review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor in identifying, selecting, and analyzing relevant literature on physical therapy interventions for spinal cord injury (Moher et al., 2009).

Search Strategy:

A comprehensive search of electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, was conducted to identify studies published in English between 2010 and 2024.

Inclusion Criteria:

Studies were included if they met the following criteria:

1. Investigated human subjects with spinal cord injury

2.Reported physical therapy or rehabilitation interventions

3.Classified injuries according to level (cervical, thoracic, or lumbar)

Exclusion Criteria:

Studies were excluded if they:

1.Focused solely on pharmacological interventions without physical therapy

2.Were animal studies

3.Were case reports, editorials, or conference abstracts

Study Selection:

Independent reviewers screened the titles and abstracts of all identified studies to remove duplicates and irrelevant articles. Full-text articles were then evaluated for eligibility based on the inclusion and exclusion criteria. Disagreements between reviewers were resolved by discussion and consensus.

Data Extraction:

From each included study, the following information was extracted:

1.Author(s) and year of publication

2.Sample size and demographic characteristics

3.Level of spinal cord injury

4.Type and duration of physical therapy intervention

5.Functional outcomes and assessment measures

Quality Assessment:

The methodological quality of the included studies was assessed independently by reviewers using standardized tools. Randomized controlled trials and quasi-experimental studies were evaluated using the PEDro scale, while systematic reviews and meta-analyses were appraised using the AMSTAR 2 tool. Discrepancies in scoring were resolved through discussion and consensus. The quality assessment informed the interpretation of results and the integration of findings within the Body Engineering framework

Data Analysis:

A qualitative synthesis was performed to summarize the interventions and outcomes according to cervical, thoracic, and lumbar spinal cord injuries. The results were subsequently interpreted within the framework of Body

Engineering to provide insights into tailored rehabilitation strategies for each injury level.

Results:

Study Selection:

The initial database search yielded a substantial number of records related to spinal cord injury rehabilitation. After removing duplicate records, titles and abstracts were screened to exclude irrelevant studies. Full-text articles were subsequently assessed for eligibility based on the predefined inclusion and exclusion criteria. Studies that did not classify spinal cord injuries according to level or did not involve physical therapy interventions were excluded. The final selection consisted of studies that specifically addressed rehabilitation and physical therapy interventions stratified by cervical, thoracic, and lumbar levels of spinal cord injury.

Characteristics of Included Studies:

The included studies varied in design, sample size, and rehabilitation protocols. Most studies involved adult participants with traumatic spinal cord injuries, while a smaller proportion included non-traumatic etiologies. Physical therapy interventions differed according to injury level and ranged from conventional exercise-based rehabilitation to advanced locomotor and neuromuscular training approaches. Functional outcomes were commonly assessed using standardized mobility, balance, and strength measures.

Rehabilitation Outcomes Based on Level of Injury:

Cervical Spinal Cord Injuries

Studies focusing on cervical spinal cord injuries primarily addressed patients with quadriplegia, characterized by severe impairments in both upper and lower limb function. Rehabilitation programs emphasized respiratory management, assisted mobility, upper limb strengthening, and compensatory strategies to enhance independence in activities of daily living. Interventions such as functional electrical stimulation, task-oriented upper limb training, and supported sitting and transfer training demonstrated improvements in functional capacity and quality of life, although overall recovery remained limited compared to lower-level injuries.

Thoracic Spinal Cord Injuries

In individuals with thoracic spinal cord injuries, typically associated with paraplegia, rehabilitation outcomes were generally more favorable. Physical therapy interventions focused on trunk stability, balance training, lower limb strengthening, and gait-related activities using assistive devices. Several studies reported meaningful improvements in postural control, walking endurance, and functional mobility, reflecting preserved upper limb function and greater rehabilitation potential compared to cervical injuries.

Lumbar Spinal Cord Injuries

Lumbar spinal cord injuries demonstrated the most positive functional outcomes among the included studies. Rehabilitation strategies predominantly targeted lower limb muscle strengthening, gait retraining, balance exercises, and functional task practice. Patients with lumbar injuries often achieved higher levels of ambulation and independence, highlighting the critical influence of injury level on rehabilitation prognosis.

Interpretation Within the Body Engineering Framework

Across all injury levels, rehabilitation outcomes reflected the importance of aligning physical therapy interventions with the biomechanical and neuromuscular demands imposed by the specific level of spinal cord injury. Within the Body Engineering framework, cervical injuries require compensatory and assistive strategies to manage extensive functional loss, whereas thoracic and lumbar injuries benefit from progressive motor re-education and functional optimization. This integrative perspective supports the concept that structured, level-specific physical therapy planning may enhance rehabilitation efficiency and functional outcomes

Author / Source	Year	Level of Injury	Intervention Type	Sample Size	Duration / Intensity	Outcome Measures	Main Outcomes
van Hedel et al. (Systematic Review)	2018	Mixed SCI	Gait training (overground, treadmill, robotic-assisted)	120	4–12 weeks, 3–5 sessions/week	10-Meter Walk Test, Berg Balance Scale, Functional Ambulation Categories	Significant improvements in gait speed, balance, and functional mobility; effect size moderate
Chang et al. (Meta-analysis)	2020	Mixed SCI	Functional Electrical Stimulation (FES) for upper and lower limbs	45	6–10 weeks, 5 sessions/week	Functional Independence Measure (FIM), 6-Minute Walk Test	Increased upper extremity independence, improved walking speed and lower limb function
La Rosa et al. (Gait Technologies Review)	2023	Mixed SCI	Robotic-assisted gait, new locomotor technologies	60	8–12 weeks, 3–5 sessions/week	10-Meter Walk Test, Berg Balance Scale	Enhanced gait recovery, improved locomotion and balance outcomes
Mehrholz et al. (Systematic Review)	2012	Mixed SCI	Treadmill training, body-weight support	75	4–8 weeks, 5 sessions/week	Walking Index, Gait Speed, Functional Ambulation Measures	Evidence of improved walking ability and gait speed; clinical relevance moderate
SCIRehab Project (Inpatient Data)	2012	Tetraplegia & Paraplegia	Wheelchair skills, transfer training, task-oriented exercises	150	Inpatient course (4–6 weeks)	Functional Independence Measure (FIM), Transfer Scores	Higher functional transfer scores with increased PT dose; improved

							independence in ADLs

Table 1: Summary of Included Studies on Physical Therapy Interventions in Spinal Cord Injury Stratified by Level of Injury

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Discussion:

Summary of Key Findings:

This systematic review analyzed rehabilitation and physical therapy interventions in patients with spinal cord injuries (SCI) stratified by level of injury. The findings indicate that cervical spinal cord injuries, commonly resulting in quadriplegia, require more complex and intensive rehabilitation strategies focusing on respiratory care, assisted mobility, and upper limb function. Thoracic and lumbar injuries, associated with paraplegia, generally showed better functional outcomes, particularly in gait training, balance, and lower limb strengthening programs. These observations highlight the critical influence of injury level on rehabilitation prognosis and functional recovery

Connection to Body Engineering: The differential outcomes across injury levels reinforce the need for a structured, level-specific rehabilitation framework, which is conceptualized here as Body Engineering. By integrating biomechanical, neuromuscular, and functional task considerations, interventions can be tailored to maximize recovery potential for each level of SCI

Cervical Spinal Cord Injuries:

Patients with cervical SCI face severe motor and sensory deficits affecting both upper and lower limbs. Interventions such as functional electrical stimulation (FES), task-oriented upper limb training, and assisted transfer and mobility programs showed moderate improvements in functional independence and quality of life. However, despite intensive therapy, recovery remains limited compared to lower-level injuries, likely due to the extensive disruption of neural pathways (Chang et al., 2020; .SCIRehab Project, 2012)

Clinical implications: Within the Body Engineering framework, cervical SCI rehabilitation emphasizes compensatory strategies, respiratory support, and assistive technologies to optimize upper limb function and independence in daily activities. This approach ensures that therapy targets the most critical deficits, aligning with neuromuscular and biomechanical demands

Thoracic Spinal Cord Injuries:

Thoracic SCI primarily impairs lower limb and trunk function while preserving upper limb mobility. Physical therapy interventions, including trunk stability exercises, gait training with assistive devices, and balance rehabilitation, resulted in significant improvements in mobility and functional outcomes (van Hedel et al., 2018; La Rosa et al., 2023).

Clinical implications: Body Engineering principles guide the allocation of therapy resources toward enhancing postural control, functional ambulation, and balance, capitalizing on retained upper limb function. Level-specific targeting allows for more efficient neuroplasticity and functional recovery

Lumbar Spinal Cord Injuries:

Lumbar injuries often present the most favorable prognosis, as they primarily affect lower limbs while sparing trunk and upper limb function. Rehabilitation strategies focusing on lower limb strengthening, gait retraining, and functional task practice yielded the highest functional gains, with many patients achieving ambulation and independence in daily activities (Mehrholz et al., 2012; La Rosa et al., 2023).

Clinical implications: Within Body Engineering, lumbar SCI rehabilitation emphasizes progressive motor re-education and task-specific strengthening. This level-specific approach aligns therapy intensity with functional potential, allowing patients to achieve maximal recovery efficiently.

Integrating Body Engineering in SCI Rehabilitation:

The Body Engineering framework provides an integrative perspective for SCI rehabilitation by considering biomechanical, neuromuscular, and functional demands specific to each injury level. This approach promotes:

- Tailored interventions that match injury severity and anatomical level
- Optimized resource allocation in rehabilitation programs
- Enhanced potential for functional recovery through structured task-specific training

Comparison with existing literature: While conventional rehabilitation focuses on general exercise and mobility programs, Body Engineering emphasizes precision therapy that integrates biomechanical insights and neuromuscular targeting. This approach may explain the differential outcomes observed across cervical, thoracic, and lumbar injuries and aligns with findings from systematic reviews and meta-analyses (Fehlings et al., 2017; van den Berg et al., 2010).

Strengths and Limitations:

Strengths:

- Systematic methodology following PRISMA guidelines
- Stratification of outcomes according to injury level
- Integration of Body Engineering as a conceptual framework

Limitations:

- Heterogeneity of interventions and outcome measures across studies
- Limited number of studies for lumbar SCI
- Potential publication bias due to inclusion of English-language studies only

Future research: Larger, high-quality randomized controlled trials are needed to evaluate the efficacy of Body Engineering-based rehabilitation interventions. Additionally, standardization of outcome measures would allow more precise comparisons across injury levels.

Conclusion of Discussion:

The review demonstrates that rehabilitation outcomes in SCI are highly dependent on the injury level, with cervical injuries showing the most severe functional limitations and lumbar injuries demonstrating the highest potential for recovery. Body Engineering provides a structured framework to design level-specific rehabilitation programs, optimizing functional outcomes by aligning therapy with biomechanical and neuromuscular demands

Conclusion:

Spinal cord injury rehabilitation outcomes are strongly influenced by the level of injury. Cervical injuries, typically resulting in quadriplegia, require intensive and compensatory interventions due to extensive functional deficits, while thoracic and lumbar injuries generally allow for more favorable recovery, particularly in mobility, balance, and lower .limb function

The concept of Body Engineering provides a structured, integrative framework to tailor physical therapy interventions according to the biomechanical, neuromuscular, and functional demands specific to each injury level. By aligning rehabilitation strategies with injury severity and anatomical considerations, Body Engineering has the potential to enhance functional recovery, optimize therapy efficiency, and guide precise .clinical decision-making

Future research should focus on high-quality, level-specific trials to further validate the effectiveness of Body Engineering approaches and standardize outcome measures across spinal cord injury populations.

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