



Original Article

# The Future of Physical Therapy: Integrating Robotics and Exoskeletons in Rehabilitation Protocols

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**Abstract** - The integration of robotics and exoskeletons in physical therapy is poised to revolutionize rehabilitation protocols, enhancing both patient outcomes and the efficiency of therapeutic practices. Recent advancements in robotic technology have led to the development of devices that assist in the rehabilitation of patients with various physical impairments, including those recovering from strokes or spinal cord injuries. These devices can perform repetitive movements, allowing for consistent training and increased therapy duration without overburdening therapists. Robotic systems, particularly exoskeletons, provide tailored support for upper and lower limb rehabilitation, improving range of motion and facilitating gait training. They enable therapists to supervise multiple patients simultaneously, thereby addressing the growing demand for rehabilitation services. Furthermore, the automation of therapy sessions through telerehabilitation platforms allows for remote monitoring and assessment, making rehabilitation more accessible. Despite challenges such as cost and technology integration, the benefits of robotic-assisted therapy including improved patient motivation and adherence are significant. As research continues to evolve, the future of physical therapy will likely see a greater emphasis on these technologies, fundamentally transforming rehabilitation practices and enhancing patient recovery trajectories.

**Keywords** - Robotics, Exoskeletons, Rehabilitation, Physical Therapy, Telerehabilitation, Patient Outcomes.

## 1. Introduction

The field of physical therapy is undergoing a transformative shift, driven by advancements in technology. Among the most promising developments are robotics and exoskeletons, which are increasingly being integrated into rehabilitation protocols. These innovations not only enhance the effectiveness of therapy but also address significant challenges faced by healthcare providers in delivering quality rehabilitation services.

### 1.1. The Need for Innovation in Rehabilitation

Traditional physical therapy methods often rely on manual techniques and patient participation, which can vary significantly among individuals. This variability can lead to inconsistent outcomes and prolonged recovery times, especially for patients with severe impairments. Moreover, the growing aging population and the rising incidence of chronic conditions necessitate more efficient rehabilitation solutions. As a result, there is an urgent need for innovative approaches that can provide standardized care while accommodating the unique needs of each patient.

### 1.2. Advancements in Robotics and Exoskeletons

Robotic-assisted therapy and exoskeletons represent a significant leap forward in rehabilitation technology. Robotic devices can deliver precise, repetitive movements that are essential for motor learning and recovery. These systems are designed to assist patients in performing exercises that might be too challenging or painful without support. Exoskeletons, in particular, offer both upper and lower limb assistance, enabling individuals with mobility impairments to regain independence and improve their functional abilities. The integration of these technologies into rehabilitation protocols has shown promising results in clinical studies. For instance, robotic systems have been associated with faster recovery times and improved muscle strength compared to traditional therapy methods. Additionally, they provide real-time feedback to both patients and therapists, facilitating more personalized treatment plans.

## 2. Technological Advancements in Rehabilitation

The integration of advanced technologies, particularly robotics and exoskeletons, is reshaping rehabilitation practices. These innovations not only enhance treatment efficacy but also improve patient engagement and outcomes.

## 2.1. Robotics in Physical Therapy

### 2.1.1. Overview of Robotic Systems Used in Rehabilitation

Robotic systems in physical therapy are designed to assist patients in performing therapeutic exercises with precision and consistency. These devices can be categorized into two main types: end-effector robots and exoskeletons. End-effector robots connect to the patient's limb at a distal point, allowing for specific joint movements, while exoskeletons provide support at multiple joints, guiding the patient through a pre-programmed trajectory.

### 2.1.2. Examples and Applications in Therapy

Robotic systems have been effectively utilized in various therapeutic applications:

- **Gait Training:** Robotic gait training systems, such as the Lokomat, assist patients with mobility impairments by providing support and mimicking natural walking patterns. This technology is particularly beneficial for individuals recovering from strokes or spinal cord injuries.
- **Upper Limb Rehabilitation:** Devices like the Armeo Spring are designed to help patients regain arm function after neurological injuries. They provide resistance and feedback, allowing for repetitive practice of movements essential for daily activities.
- **Neuroplasticity Stimulation:** Robotic therapy has been shown to enhance neuroplasticity, helping patients develop new neural pathways through consistent practice of targeted movements. This is crucial for those with conditions like Parkinson's disease or traumatic brain injuries.

The benefits of robotic-assisted rehabilitation include increased treatment intensity, reduced therapist workload, and improved patient motivation through interactive interfaces that gamify the rehabilitation process.

## 2.2. Exoskeleton Technology

### 2.2.1. Types of Exoskeletons (Active vs. Passive)

Exoskeletons can be classified into two primary categories: active and passive.

- **Active Exoskeletons:** These devices are powered by motors or actuators that assist or enhance the user's movements. They are typically used for rehabilitation purposes, allowing patients to engage in exercises that would otherwise be difficult or impossible due to their condition.
- **Passive Exoskeletons:** These rely on springs or other mechanical systems to provide support without active power sources. They are often used to assist with posture or reduce fatigue during activities.

### 2.2.2. Evolution and Advancements in Exoskeletons for Rehabilitation

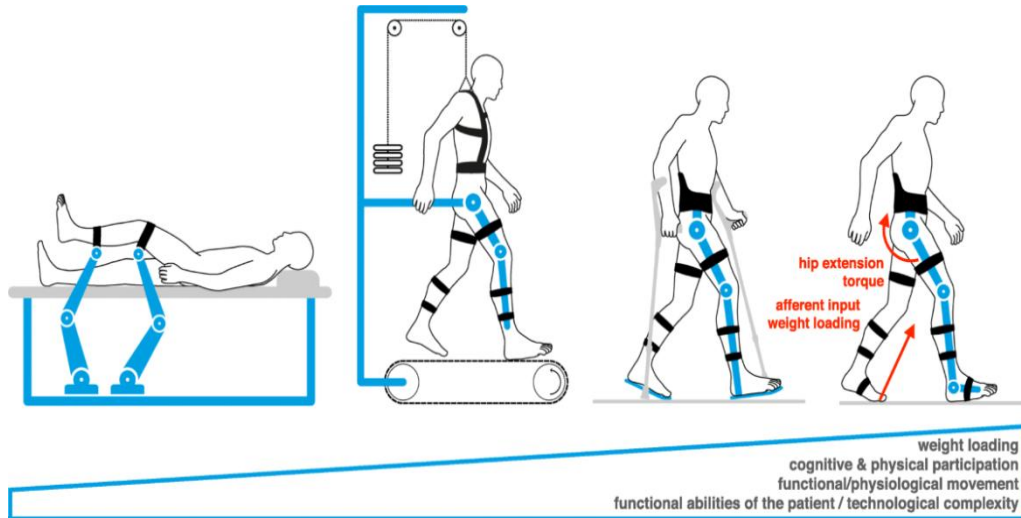
The evolution of exoskeleton technology has seen significant advancements over recent years. Early models were bulky and limited in functionality; however, modern designs focus on user comfort, portability, and adaptability. Innovations include lightweight materials and advanced control systems that allow for seamless integration with the user's movements. Recent developments have also introduced smart features that enable real-time feedback and data collection during therapy sessions. This capability allows therapists to tailor rehabilitation programs based on individual patient progress, enhancing the overall effectiveness of treatment.

## 3. Integration of Robotics and Exoskeletons in Therapy Protocols

The integration of robotics and exoskeletons into therapy protocols is transforming rehabilitation practices across various clinical applications. This section explores the clinical applications, benefits, and challenges associated with these technologies.

### 3.1. Clinical Applications

The progressive integration of robotics and exoskeletons in rehabilitation therapy. It depicts the transformation from passive weight-bearing exercises to active, functional movements facilitated by robotic systems and exoskeletons. In the first phase, the patient is shown in a reclined position on a robotic device, emphasizing passive joint movement and weight-bearing without active participation. This stage aims to enhance mobility and reduce stiffness while preventing atrophy in the early stages of recovery. The subsequent phases demonstrate the patient progressing to upright walking with the support of an exoskeleton and additional assistive devices, such as treadmills. The image highlights the importance of weight distribution, afferent sensory input, and hip extension torque, which are key biomechanical elements in restoring a natural gait. This gradual increase in functional abilities mirrors the patient's physiological recovery and adaptation to the robotic assistance. Finally, the image underscores the collaboration between the patient's cognitive and physical capabilities and the technological sophistication of the exoskeleton system. As therapy progresses, patients achieve greater independence in movement, bridging the gap between assisted and unassisted mobility. This visual serves as an effective tool to convey the dynamic interplay of technology and human physiology in modern rehabilitation practices.



**Fig 1: Stages of Robotic-Assisted Rehabilitation**

### 3.1.1. Stroke Rehabilitation

Robotic systems are increasingly used in stroke rehabilitation to aid recovery of motor function and mobility. Devices like the Lokomat provide gait training by assisting patients in walking patterns, which is essential for neuroplasticity and motor learning. Studies have shown that robotic-assisted therapy can lead to improvements in independence and muscle strength, although changes in lower limb motor function may vary among individuals<sup>14</sup>.

### 3.1.2. Neurological Disorders

Robotics play a crucial role in the rehabilitation of patients with neurological disorders such as spinal cord injuries (SCI) and multiple sclerosis. Exoskeletons allow individuals with severe mobility impairments to engage in standing and walking activities, promoting physical activity and reducing the risks associated with prolonged sitting. Research indicates that these devices can enhance muscle strength, reduce spasticity, and improve overall quality of life for patients.

### 3.1.3. Orthopedic Recovery

In orthopedic recovery, robotic devices assist in rehabilitation following surgeries or injuries. They provide controlled motion to support joint healing while allowing patients to perform therapeutic exercises safely. For instance, robotic arms can facilitate precise movements during rehabilitation, helping patients regain range of motion and strength post-surgery.

## 3.2. Benefits of Integration

### 3.2.1. Improved Outcomes

The integration of robotics and exoskeletons into therapy protocols has been associated with improved clinical outcomes. These technologies facilitate higher repetition rates of therapeutic exercises, which are essential for effective rehabilitation. Studies have demonstrated that patients using robotic systems often show significant gains in functional independence and strength compared to traditional therapy methods.

### 3.2.2. Enhanced Patient Engagement

Robotics can enhance patient engagement through interactive interfaces that gamify the rehabilitation experience. Patients are more likely to participate actively in their recovery when they find the therapy enjoyable and motivating. This increased engagement leads to better adherence to rehabilitation programs and ultimately improves outcomes.

### 3.2.3. Reduction in Therapist Workload

The use of robotics allows therapists to manage multiple patients simultaneously while providing high-quality care. With patients strapped into robotic devices, therapists can focus on monitoring progress rather than delivering manual therapy. This shift not only alleviates the physical burden on therapists but also optimizes the efficiency of rehabilitation services.

### 3.3. Challenges and Limitations

#### 3.3.1. Cost and Accessibility

One of the primary challenges facing the integration of robotics and exoskeletons in therapy is their high cost. Many healthcare facilities may struggle to afford these advanced technologies, limiting their availability to patients who could benefit from them. Additionally, insurance coverage for robotic-assisted therapies remains inconsistent across regions.

#### 3.3.2. Training and Adaptation for Therapists and Patients

Effective use of robotic systems requires specialized training for both therapists and patients. Therapists must learn how to operate these devices effectively while also adapting their therapeutic approaches to incorporate technology into traditional practices. Patients may need time to adjust to using robotic devices, which could impact their initial willingness to engage with the technology.

#### 3.3.3. Ethical and Regulatory Considerations

The rapid development of robotic technologies raises ethical questions regarding patient safety, data privacy, and informed consent. Regulatory frameworks must evolve alongside technological advancements to ensure that these devices are safe and effective for clinical use. Ongoing research is needed to address these ethical considerations while maximizing the benefits of robotics in rehabilitation.

## 4. Case Studies and Practical Applications

The integration of robotics and exoskeletons in rehabilitation has been substantiated through various case studies and practical applications, showcasing their effectiveness across different patient populations. This section highlights notable examples from clinical practice, demonstrating the impact of these technologies on rehabilitation outcomes.

### 4.1. Case Study 1: Robotic Exoskeleton for Stroke Rehabilitation

A significant case study involved a 52-year-old female patient with a nine-year history of chronic stroke. The patient underwent 20 therapy sessions using a novel electromechanical robotic exoskeleton designed for distal joint rehabilitation. The therapy sessions lasted 45 minutes each, focusing on wrist and hand movements. Pre- and post-therapy assessments included clinical scales such as the Fugl-Meyer (FM) and the Barthel Index (BI), alongside neurophysiological measures of cortical excitability.

#### 4.1.1. Results

Fugl-Meyer Upper Extremity Score: Increased from baseline by 9 units.

- **Barthel Index:** Improved from 85 to 95, indicating enhanced functional independence.
- **Modified Ashworth Scale:** Decreased spasticity from a score of 3 to 2.
- **Motor Evoked Potential (MEP):** Increased by 98  $\mu$ V for ipsilesional responses, reflecting improved cortical activation.

**Table 1: Clinical Measures Pre- and Post-Therapy Changes**

Clinical Measure	Pre-Therapy	Post-Therapy	Change
Fugl-Meyer Score	X (baseline)	X + 9	Increase
Barthel Index	85	95	Increase
Modified Ashworth Scale	3	2	Decrease

### 4.2. Case Study 2: AI-Based Exoskeleton for Lower Limb Rehabilitation

Another innovative application involves the use of AI-driven exoskeletons for lower limb rehabilitation in patients with spinal cord injuries. A recent study incorporated a master-slave exoskeletal system designed for mirror therapy. This system allowed the functional limb to guide the impaired limb through therapeutic exercises, effectively stimulating muscle activation and promoting recovery.

#### 4.2.1. Key Features

- **Real-Time Feedback:** The system utilized multi-channel sensing to monitor muscle activation and user emotions, enhancing therapeutic engagement.
- **Reinforcement Learning:** The control algorithms adapted to the patient's movements, ensuring personalized therapy that adjusted dynamically to individual progress.

#### 4.2.2. Practical Application: Hybrid Assistive Limb (HAL)

The Hybrid Assistive Limb (HAL) by Cyberdyne exemplifies practical applications of exoskeleton technology in rehabilitation. HAL is designed for patients with spinal cord injuries and other neuromuscular disorders. It captures brain signals through sensors placed on the legs, translating these signals into movement assistance.

#### 4.2.3. Outcomes

Patients using HAL have reported improvements in mobility and independence. The technology has been successfully implemented in both clinical settings and home environments, showcasing versatility in rehabilitation applications. This case illustrates how robotic exoskeletons can significantly enhance functional recovery and quality of life for individuals with severe mobility impairments.

#### 4.3. Conclusion

The case studies presented highlight the transformative potential of robotics and exoskeletons in rehabilitation protocols. By facilitating targeted therapy and enhancing patient engagement, these technologies are paving the way for more effective rehabilitation strategies that can adapt to individual needs. As research continues to advance, the integration of robotics into clinical practice will likely become more widespread, offering new hope for patients recovering from various physical impairments.

### 5. Future Directions in Physical Therapy

The future of physical therapy is being shaped by emerging technologies, personalized rehabilitation protocols, and potential collaborations among various stakeholders. These advancements promise to enhance patient care, improve outcomes, and create a more efficient rehabilitation process.

#### 5.1. Emerging Technologies

##### 5.1.1. Artificial Intelligence and Machine Learning in Robotics

Artificial Intelligence (AI) and machine learning are revolutionizing physical therapy by enabling the development of intelligent systems that can analyze vast amounts of data. These technologies assist in diagnostics, treatment planning, and outcome prediction. For instance, AI algorithms can evaluate patient data from wearable devices to identify patterns that inform personalized rehabilitation strategies. This capability enhances the precision of interventions and allows for timely adjustments based on real-time feedback.

**Table 2: Technologies in Rehabilitation and Their Benefits**

Technology	Application	Benefits
AI in Diagnostics	Analyzing patient data for accurate assessments	Improved diagnostic accuracy
Machine Learning	Customizing rehabilitation programs	Enhanced personalization of treatment plans
Predictive Analytics	Forecasting patient outcomes	Proactive intervention strategies

##### 5.1.2. Wearable Sensors and Data Analytics

Wearable technology is becoming increasingly integral to physical therapy. Devices such as smartwatches and fitness trackers provide real-time data on patient movement, muscle activity, and physiological responses during rehabilitation exercises. This data can be analyzed to track progress, adjust therapy intensity, and ensure adherence to prescribed exercises. The integration of wearable sensors facilitates continuous monitoring, allowing therapists to intervene promptly if a patient's performance deviates from expected patterns. This capability not only enhances treatment effectiveness but also empowers patients by providing them with insights into their recovery journey.

**Table 3: Impact of Wearable Technology on Rehabilitation Therapy**

Wearable Technology	Functionality	Impact on Therapy
Smart Sensors	Monitor movement and muscle activity	Real-time feedback for therapists
Fitness Trackers	Track daily activity levels	Encourages patient engagement and adherence
Mobile Health Apps	Provide exercise reminders and progress tracking	Enhances accountability in rehabilitation



## 5.2. Personalized Rehabilitation Protocols

Personalized rehabilitation protocols are becoming a cornerstone of modern physical therapy. The integration of robotics allows therapists to tailor treatment plans to individual patient needs more effectively than ever before.

### 5.2.1. Tailoring Therapy to Individual Needs Using Robotics

Robotic systems can adapt to the specific capabilities and limitations of each patient. For example, robotic exoskeletons can adjust resistance levels based on real-time performance metrics, ensuring that exercises remain challenging yet achievable. This adaptability is crucial for optimizing recovery outcomes, as it promotes engagement while minimizing the risk of injury. Additionally, AI-driven analytics can help therapists design customized exercise regimens based on a patient's unique medical history, physical condition, and recovery goals. By leveraging data from wearable sensors, therapists can refine these plans dynamically throughout the rehabilitation process.

**Table 4: Personalization Aspects in Robotic-Assisted Rehabilitation**

Personalization Aspect	Description	Benefits
Adaptive Robotics	Robots adjust support/resistance during therapy	Tailored challenges for optimal recovery
AI-Driven Analytics	Data analysis informs individualized plans	Enhanced precision in treatment interventions
Continuous Feedback Loop	Real-time adjustments based on performance	Improved engagement and adherence

## 5.3. Potential Collaborations

The future of physical therapy will benefit from collaborations between engineers, clinicians, and researchers. Such partnerships are essential for advancing technology integration into clinical practice.

### 5.3.1. Partnerships Between Engineers, Clinicians, and Researchers

Collaborative efforts can lead to the development of innovative solutions that address specific challenges in rehabilitation. For instance, engineers can work with clinicians to design user-friendly robotic devices that meet the practical needs of patients while ensuring safety and efficacy. Researchers can contribute by conducting studies that validate the effectiveness of new technologies in diverse patient populations. These collaborations also foster interdisciplinary knowledge exchange, enabling professionals from different fields to share insights that enhance therapeutic practices. As technology continues to evolve rapidly, ongoing partnerships will be crucial for ensuring that innovations are effectively translated into improved patient care.

**Table 5: Collaborative Efforts in Rehabilitation Technology Development**

Collaboration Type	Stakeholders Involved	Outcomes Expected
Engineering-Clinical Teams	Engineers and physical therapists	Development of practical robotic solutions
Research Partnerships	Academics and healthcare providers	Evidence-based validation of new technologies
Interdisciplinary Workshops	Various professionals sharing expertise	Enhanced understanding of integrated care approaches

## 6. Conclusion

The integration of robotics and exoskeletons into physical therapy represents a significant advancement in rehabilitation practices, offering innovative solutions to enhance patient outcomes and improve the efficiency of therapeutic interventions. As demonstrated through various case studies and practical applications, these technologies have shown promise in addressing the unique challenges faced by individuals recovering from strokes, neurological disorders, and orthopedic injuries. By facilitating targeted, repetitive movements and providing real-time feedback, robotic systems not only aid in physical recovery but also promote neuroplasticity, which is crucial for regaining lost functions. Emerging technologies such as artificial intelligence and wearable sensors further enhance the capabilities of robotic systems in rehabilitation. AI-driven analytics allow for the personalization of therapy protocols, tailoring interventions to meet the specific needs of each patient. Wearable devices enable continuous monitoring of patient progress, ensuring that therapists can make timely adjustments to treatment plans based on real-time data. This level of customization not only improves engagement but also empowers patients to take an active role in their recovery journey.

However, the successful integration of these advanced technologies into clinical practice does not come without challenges. Issues such as high costs, accessibility, and the need for specialized training for both therapists and patients must be addressed to ensure widespread adoption. Additionally, ethical considerations surrounding patient safety and data privacy remain paramount as these technologies evolve. Collaborative efforts among engineers, clinicians, and researchers will be essential in overcoming these obstacles, fostering innovation while ensuring that patient care remains at the forefront. In conclusion, the future of physical therapy is bright, characterized by a shift towards more personalized, data-driven approaches facilitated by robotics and exoskeletons. As research continues to advance and interdisciplinary collaborations flourish, the potential for improved rehabilitation outcomes becomes increasingly attainable. Embracing these innovations will not only enhance the quality of care provided to patients but also redefine the landscape of physical therapy as a whole, paving the way for a more effective and engaging rehabilitation experience.

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