Review

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Robotics in Physical Rehabilitation—Review

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Abstract: As the global population faces an increasing prevalence of physical disabilities, the challenge of motor rehabilitation has become increasingly urgent. Considering that approximately 15% of the global population lives with some form of disability, with a significant number having motor disabilities that greatly impact their quality of life, the integration of robotic technologies into rehabilitation processes offers an opportunity for significant improvement in functional recovery and patient autonomy. This analysis aims to evaluate the progress and challenges encountered in implementing robotic technology for the rehabilitation of patients with physical disabilities, highlighting the potential of emerging technologies such as exoskeletons, assisted training devices, and brain-computer interface systems in facilitating motor recovery. By examining relevant clinical studies, the analysis demonstrates the varied effectiveness of robotic therapies compared to traditional rehabilitation methods, while also highlighting the need for ongoing research to optimize care practices and address challenges related to cost, accessibility, and treatment personalization. In conclusion, robotic technologies represent a promising direction in motor rehabilitation, with the potential to revolutionize the care of patients with physical disabilities, significantly improving quality of life and social integration.

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1. Introduction

According to the World Health Organization, approximately 15% of the global population, over 1 billion people, live with some form of disability, of which between 110 and 190 million experience significant difficulties in functioning [1]. Among these, motor disabilities constitute a significant portion, having a major impact on individual quality of life and, consequently, on global health and social care systems. Motor disabilities can result from a variety of causes, including strokes, traumatic craniocerebral injuries, neurological conditions such as multiple sclerosis and degenerative diseases, accidents, or injuries. The impact of these disabilities is profound, limiting individuals' ability to perform essential daily activities such as walking, bathing, eating, or dressing, leading to a decrease in autonomy and quality of life. Beyond the physical impact, motor disabilities often bring significant psychological costs, contributing to an increased incidence of anxiety and depression among patients. The emotional impact of adapting to a new post-traumatic or post-diagnostic reality can be profound, affecting self-esteem and the quality of social interactions for those affected. Studies show that approximately one-third of patients who suffer from strokes develop major depression post-stroke, emphasizing the acute need for integrated, effective rehabilitation approaches that address both the physical and psychological needs of patients [2].

The increasing prevalence of motor disabilities, accompanied by population aging in many countries, puts growing pressure on healthcare and social assistance systems. In this context, motor rehabilitation and robotic care become a priority, with a focus on the development and implementation of innovative technologies to support recovery and improve quality of life.

A primary goal of rehabilitation is to restore or improve the motor function of patients, through specific exercises, physical therapy, and the use of advanced technology such as robotic systems, patients can achieve significant improvements in strength, coordination, and dexterity. By recovering motor abilities, patients can perform daily activities independently, from dressing, moving and

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feeding themselves. This increased independence is crucial for self-esteem and the social integration of patients.

Motor rehabilitation stimulates neuroplasticity, the brain's ability to reorganize and form new neural connections in response to learning and experience. Repeated and controlled therapies can facilitate the relearning of lost motor skills and contribute to functional recovery after injuries to the nervous system.

The impact of motor rehabilitation extends beyond physical benefits, also positively affecting the psychological state of patients. Improvements in the ability to perform independent activities and progress observed during therapy can reduce feelings of frustration, anxiety, and depression associated with disabilities. Motor rehabilitation also helps prevent secondary complications such as muscle contractures, muscle atrophy, and joint deterioration. By maintaining and improving mobility, rehabilitation contributes to overall health maintenance and prevents further deterioration of patients' conditions.

An essential component of successful motor rehabilitation is customizing therapy to adapt to the specific needs and goals of each patient. Careful assessment and collaboration between patients, therapists, and other medical professionals enable the development of individualized treatment plans that maximize the potential for recovery.

In recent years, advances in robotics and artificial intelligence have opened new perspectives for motor rehabilitation, offering hopes for more effective and personalized treatments. Robotic systems, from exoskeletons to end-effector-based assisted training devices, introduce a level of precision, repeatability, and adaptability unprecedented in traditional therapy and promise significant improvements, while also providing sensory and motor feedback. They allow for controlled and personalized therapeutic exercises tailored to the progress and needs of each patient, contributing to more efficient individual recovery. By providing visual, auditory, and haptic feedback during therapeutic exercises, robotic systems support and amplify the process of neuroplasticity [3]. This means that patients are better equipped to relearn lost movements and improve their motor function.

Robotic technologies enable precise and real-time monitoring of patient performance and progress. This data can be used to adjust and optimize therapy, ensuring that patients receive the optimal level of assistance and challenge throughout rehabilitation sessions.

Rehabilitation has been transformed into a more engaging and motivating experience for patients by integrating elements of gaming and virtual reality into exercises. This playful approach can improve treatment adherence and contribute to the emotional and psychological well-being of patients.

Implementing robotic systems in motor rehabilitation and care for patients with physical disabilities can reduce the workload of therapists, allowing them to focus on aspects that require direct and personalized human intervention. This can improve the overall efficiency of the rehabilitation and care process, enabling the treatment of a larger number of patients in the same time frame. Despite these advantages, introducing robotic technology into motor rehabilitation poses challenges, including the high costs of equipment, the need for specialized staff training, and the adaptation of clinical infrastructure. The significant potential for improving patient outcomes justifies investments in research and development in this field. In this context, the DDSKILLS (Digital and Social Skills for All) project exemplifies a commitment to harnessing emerging technologies to support both professional caregivers and individuals with disabilities. DDSKILLS has developed training courses focused on improving the digital skills of caregivers to more effectively use new technologies and support individuals with disabilities in their use [4].

Beyond the significant physical and psychological impact, integrating emerging technologies, including wearable technology and the Internet of Things (IoT), opens new horizons for continuous and personalized patient monitoring, promising to revolutionize motor rehabilitation.

As we face the challenges of implementing robotic technology in clinical settings, we recognize the importance of rigorous evaluation of its impact through detailed clinical studies and the development of effective strategies to facilitate widespread adoption. The objective is for innovations to become accessible and beneficial to a broad spectrum of patients, transforming technological

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potential into a tangible reality in patient care. This commitment to exploring and implementing innovative solutions underscores the opportunities that robotic technology offers to shape the future of motor rehabilitation, enhancing the quality of therapeutic interventions and contributing to a future where every patient has the chance for an improved life [5].

2. Objectives and Methodology

The overall objective of the study is to conduct an in-depth investigation of how innovations in robotics can facilitate motor recovery and help reduce the workload of caregiving staff, thereby improving the quality of life for patients with physical disabilities, establishing the following specific objectives.

- Exploring the diversity of robotic technologies applied in motor recovery, from exoskeletons and robotic arms to personal assistant robots and brain-computer interfaces;
- Analyzing the advantages and limitations of each category of robotic systems in the specific context of motor recovery;
- Investigating the technical, economic, social, and cultural barriers that may limit access to or acceptance of robotic technology for motor recovery;
- Identifying facilitating factors that promote the adoption of robotic technologies, including funding initiatives, training programs for medical staff, and awareness campaigns.
- By achieving these objectives, the study provides a solid foundation for understanding the complexity and potential of robotic technologies in improving the motor recovery process and supporting patients with motor disabilities. It contributes to the development of effective implementation strategies and the optimization of care practice

To ensure comprehensive coverage of relevant literature, scientific databases and reputable sources of information known for the quality and diversity of publications on robotic technology in motor rehabilitation and patient care were selected. The search strategy employed a combination of keywords and relevant phrases related to robotic technology and motor recovery, along with logical operators to refine searches and enhance the relevance and precision of results.

Inclusion criteria were established to ensure the selection of studies directly addressing the research objectives. These criteria included studies that:

- Report on the use of robotic systems in motor recovery or patient care for individuals with physical disabilities;
- Review and analyze published solutions with empirical data;
- Published in the last 15 years to ensure the relevance of the information.

The exclusion criteria eliminated studies that:

- Do not focus on the use of robotic technology in motor rehabilitation;
- Opinion articles, reviews, or editorials without empirical data;
- Studies conducted on animals or that did not involve human subjects.

The selection process was carried out in stages, initially screening titles and abstracts to identify potentially relevant studies. Subsequently, the full texts of these studies were thoroughly evaluated, applying inclusion and exclusion criteria, to determine their final eligibility for analysis.

Table 1.

Type	Description	Reference
Systematic reviews and meta-analyses	It synthesizes the results from multiple primary research studies on a specific topic, providing a comprehensive assessment of the availability and quality of evidence. Examines the overall effectiveness of robot-assisted therapy in upper limb or gait rehabilitation.	[6–22].

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Randomised Controlled Trials (RCTs), Case and Pilot Studies	Compares the effectiveness of an intervention with a control group in a well-structured setting with randomly selected participants. Directly tests the effects of robot-assisted intervention compared to standard rehabilitation methods. Explores the impact of interventions on individual cases or small groups, providing initial data for further research. Initial use of robotic therapies for specific patients or in preliminary settings.	[23–29].
Exploratory Studies and Technical Development Analyses	It focuses on the development, improvement and evaluation of technical aspects of robotic devices, including design and implementation. Describe technological innovations in robotic rehabilitation or analyse specific aspects of system performance. Investigates the potential and practicality of novel approaches in a research setting, often in the early stages. Tests new methodologies or technologies in rehabilitation to determine the viability of more rigorous future studies.	[30–47].
Robotic systems for patient care	Dressing, eating or washing	[48–51].

The extracted information was organized and synthesized to address the objectives set. Qualitative or quantitative analyses, as appropriate, were conducted to assess the effectiveness and impact of robotic interventions on motor recovery, while identifying trends, challenges and future research directions in this area.

3. Classification of Robotic Systems for the Rehabilitation and Care of Patients with Disabilities

The detailed classification provides a comprehensive coverage of robotic systems for motor rehabilitation, taking as criteria the objectives formulated in the previous paragraph: exploration of technologies, analysis of advantages and limitations, investigation of barriers and identification of facilitating factors.

3.1. The Diversity of Robotic Technologies Applied in Motor Rehabilitation, Including Exoskeletons, Robotic Arms, Personal Assistant Robots and Brain-Computer Interfaces, Can be Classified According to:

1. Type of assistance:

- Upper Limb Motor Rehabilitation: devices designed to assist and improve the motor function of the arms and hands, providing repetitive and controlled exercises that aid in recovery after strokes or other conditions. Examples: In-Motion robotic arms, the ARMin exoskeleton, robotic gloves such as HandSOME;

- Lower Limb Motor Rehabilitation: Robotic lower limb systems facilitate gait rehabilitation by supporting the body weight and guiding leg movements in a way that mimics natural walking. Examples: Lokomat, ReWalk exoskeleton;
- Assistance in daily activities: designed to help people with reduced mobility to perform various daily activities such as feeding, dressing, and handling objects. Examples: PR2 personal assistance robot, JACO robotic system;
- Cognitive support and social interaction: used to improve social interaction and communication skills, especially among individuals with autism or neurodegenerative conditions. Enhancing social and emotional skills; cognitive stimulation; improving well-being and reducing feelings of isolation. Examples: the PARO robot, interactive robots such as NAO and Pepper.

2. Type of rehabilitation therapy:

- Passive: the robot guides the patient's limb through a range of motions without the patient exerting any effort. This approach is essential in the early stages of rehabilitation when the patient has limited mobility or reduced muscle strength;
- Active: the patient initiates the movement, and the robot helps only when necessary. This method stimulates neuroplasticity and encourages the relearning of motor skills through active practice;
- Bilateral: involves the simultaneous use of both limbs, where the activity of a healthy limb is mirrored or assisted by the robot on the affected limb. This type of therapy is used to improve coordination and movement symmetry between the upper or lower limbs.

3. User interaction mode:

- Direct interface: allows users to interact directly with the device through physical buttons, touchpads, or gesture control. Rehabilitation systems that use touch screens or motion sensors to capture and respond to user actions, such as the Haptic Master Robotic Arm system;
- Neuromotor interface: uses the user's neurological signals for control, such as brain-computer interfaces (BCI) that enable robotic control through brain activity, facilitating rehabilitation for individuals with very limited movements, or EMG (electromyographic) sensors that detect the user's movement intentions;
- AI Adaptation: automatically adapts to the user's needs without direct intervention, using artificial intelligence algorithms to optimize therapy. Adjusts the level of assistance or resistance according to the user's progress, such as rehabilitation systems that use machine learning to customize therapeutic exercises.

4. Location of use:

- Clinical: Robots used in hospitals or rehabilitation centers, designed to provide intensive care under the direct supervision of specialists. As an example, the BRAVO exoskeleton for upper limb rehabilitation in clinical environments;
- Home-based: Robotized systems adapted for use at home, providing patients the opportunity to continue therapy in the comfort of their own residence. Robotic gloves like HandSOME are used to improve hand dexterity;
- Teletherapy: robotic systems for parameterized and remotely controlled therapy by specialists through IoT technologies.

5. Mechanical structure:

- End-effector: focuses on interaction with one or more specific parts of the body (end effectors) such as hands, legs, or head. They are used in specific rehabilitation exercises, providing assisted movement and sensory feedback. Example: Bi-Manu-Track;
- Exoskeletons: external robotic devices that are mounted on the body, providing motor support and assistance to people with disabilities. They are especially used for rehabilitating patients with paralysis or muscle weakness, facilitating movement of the upper or lower limbs through mechanical support and sometimes electrical stimulation. Examples include ARMin III and T-WREX;
- Wearable robotics: lightweight and flexible devices that can be worn on the body, providing continuous support in daily activities or rehabilitation exercises. They are ideal for long-term use, especially in home environments;
- Soft robotics: they use flexible and adaptable materials that mimic the natural movement of the human body. This category is designed to provide safer and more comfortable interaction with

the user, making it ideal for patients requiring gentle therapy and support in precision movements.

6. Type of actuators:

- Electric motors (AC/DC), the most common in robotic systems due to their precise control over speed and position. They are ideal for rehabilitation exercises that require fine adjustments of movement;
- Hydraulic and pneumatic motors provide significant forces and are often used in exoskeletons or other devices that require support for body weight. However, they are less precise than electric motors and can be more challenging to control;
- Functional Electrical Stimulation (FES) involves applying electrical impulses to muscles to induce muscle contractions. It is used in combination with robotic devices to improve muscle strength and facilitate motor retraining.

7. Control structure:

- Open-loop control: used in the initial stages of rehabilitation, where precise control is less critical. These systems operate without direct feedback, applying control actions based on a predefined set of instructions without adjusting them in real time;
- Closed-loop PID control (Proportional-Integral-Derivative): widely used due to their simplicity and ability to provide stable and efficient control for a variety of tasks;
- Robust control applied in robotic rehabilitation systems utilizes a fractional approach to control a seven degrees of freedom (DoF) exoskeleton, providing efficient management of friction dynamics and disturbances. The main advantage is its advanced ability to withstand uncertainties, parameter changes, and perturbations, such as a patient's hand tremors;
- Adaptive Control: Adaptive Control with Active Disturbance Rejection (ADRC) modifies its behavior to adapt to changes in system parameters or uncertain parameters. It is preferred for its ability to simplify the control system while providing advanced disturbance and uncertainty rejection capabilities;
- Hybrid control: combines elements of open and closed loop systems, providing flexibility in treatment by adapting to different stages of rehabilitation.

The type of control structure is not the primary focus of this work as all identified types have proven to be effective.

8. Control inputs:

- Force/Torque: transducers for the forces and torques applied by the patient or the robot, providing feedback for adjusting assistance. The major advantage arises in the measurement or generation of torque moments, which can be very precisely achieved in robotic systems compared to traditional manual therapy where this aspect is subjective;
- Optical encoders: used to measure position and angular speed, ensuring precise motion control;
- EMG signals (Electromyographic): capturing muscle activity to initiate or guide robotic movement, facilitating a more natural and intuitive interaction with the user;
- Pressure: In the case of hydraulic or pneumatic actuators, measuring pressure helps determine the applied force and appropriately adjust the assistance.

3.2. Analysis of the Advantages and Limitations of Each Category of Robotic Systems

Advantages: Precision and repeatability of movements, continuous monitoring of progress, adaptability to patient needs, potential for improving patient motivation.

Limitations: High acquisition and maintenance costs, operational complexity, the need for specific training for medical staff, limited accessibility in some regions.

Examples:

- Exoskeleton: Advantages - mobility support and intensive rehabilitation; Limitations - high cost and high weight;
- Robotic arms: Advantages - precision in fine movements; Limitations – the need for controlled and stable space for use.

3.3. Investigation of Technical, Economic, Social, and Cultural Barriers

Technical: Complexity and reliability of robotic systems, integration with other medical technologies.

Economic: Initial and maintenance costs, lack of adequate funding.

Social: Acceptance by patients and medical staff, resistance to change.

Cultural: Variations in perception of technology in different cultures, language and educational barriers

Examples:

- Technical: Need for constant calibration and maintenance.
- Economic: Limited budgets of medical institutions.
- Social: Negative perception of advanced technology in traditional communities.

3.4. Identifying Facilitative Factors for the Adoption of Robotic Technologies

Funding: Public and private funding initiatives, grants, and support programs.

Training programs: Courses and workshops for medical staff to learn how to use and maintain robotic systems.

Awareness campaigns: Informing the public and medical communities about the benefits and uses of robotic technology.

Examples:

- Funding: Government grants for the acquisition of robotic equipment;
- Training programs: Specialized courses for therapists and biomedical engineers;
- Awareness campaigns: Educational programs in the media and medical conferences.

4. Results

To understand the impact of robotic technologies on motor recovery and to compare the effectiveness of different robotic rehabilitation systems, the Fugl-Meyer Assessment (FMA) is most used. It is an essential tool in measuring post-stroke motor progress, assessing motor function, sensory function, balance, joint range of motion and joint pain. The FMA allows a detailed assessment of motor recovery, with an upper limb scale rated at up to 66 points. The motor recovery assessment provides an objective and standardized method to measure the effectiveness of various robotic rehabilitation systems [52].

Significant Results from Selected Studies:

MIT-MANUS was one of the first systems evaluated, showing improvements in upper limb motor function without significant adverse events over approximately 500 hours of operation. It was studied on a group of 96 post-stroke patients, demonstrating improvements in upper limb mobility, with positive effects observed six months after the intervention.

The RATULS (Robot-Assisted Training for the Upper Limb after Stroke) trial is one of the largest and most significant research studies dedicated to evaluating the effectiveness of robotic therapy for upper limb rehabilitation after stroke. This randomized, controlled trial with 770 participants divided into three groups was designed to provide a comprehensive overview of the benefits that robot-assisted training can offer compared to conventional therapy and standard care. The main objective of the study was to determine whether robotic therapy can improve upper limb functionality more effectively than traditional rehabilitation methods. It also aimed to assess the impact of robotic therapy on patients' quality of life, personal autonomy and degree of independence in carrying out daily activities. One group received upper limb-specific robotic therapy, the second group received intensive exercise therapy but without robot assistance, and the third group received the standard care recommended for stroke recovery. Therapy was applied over a fixed period with regular sessions and patient progress was monitored using standardized measurements, including the Fugl-Meyer Upper Extremity Assessment (FMA-UE) score. No significant differences were observed between the robotically treated group and the conventionally treated group in terms of improvement in FMA-UE scores, suggesting that robotic therapy, as applied in the study, was not superior to standard therapy in improving upper limb function. All groups showed improvements in upper limb function, indicating that intensive interventions, whether robotic or traditional, may contribute to post-stroke recovery. Although the RATULS study did not demonstrate a clear superiority of robotic therapy over traditional rehabilitation methods, the results highlight the importance of intensive and personalized therapy for post-stroke patients. The study also suggests that there may be subgroups of patients who would benefit more from certain types of therapy, highlighting the need for careful assessment and customization of the rehabilitation plan.

The ARMin exoskeleton was evaluated in a study involving 77 stroke patients, where a significant improvement in Fugl-Meyer Assessment (FMA) scores for arm and hand function was observed. ARMin III was tested in a 24-session parallel randomized trial. Results show that the FMA-UE (Fugl-Meyer Assessment-Upper Extremity) score of the robotically treated group was 2.6, 3.4, 3.4, and 3.1 at 4, 8, 16, and 34 weeks. Compared to the control group results which were 2.0, 2.6, 2.8, and 2.9 at the same time intervals, indicates a significantly greater improvement for the robotically treated group, although the difference between the two groups decreased over time.

The ReoGo device was used in a study of 44 patients, demonstrating improvements in movement coordination and hand dexterity as measured by the Box and Block hand function test and the Nine Hole Peg test.

The Bi-Manu-Track was tested on 44 patients, with results indicating an improvement in movement symmetry between the upper limbs. Patients were divided into a control group and a group treated with an Arm Trainer (AT) robot for 30 sessions, either conventional therapy (control group) or robotic therapy using Bi-Manu-Track (AT group). In the robotic AT group, the Fugl-Meyer (FM) score was 15 points higher at the end of the study and 13 points higher at the 3-month follow-up compared to the control group.

T-WREX also had a randomized controlled trial with an intervention conducted over 24 sessions. The robotically treated group saw an improvement in the FM score of 3.3 ± 2.4 ($p = 0.001$) and 3.6 ± 3.9 after a 6-month follow-up ($p = 0.005$), compared to the control group's FM improvement of 2.2 ± 2.6 ($p = 0.004$) and 1.5 ± 2.7 after a 6-month follow-up ($p = 0.06$).

In a secondary analysis of data from the multicenter VA-ROBOTICS study, the effectiveness of intensive therapy, including both robot-assisted therapy and intensive conventional therapy, was examined compared to standard care in improving motor function in chronic stroke patients. The research included 127 patients with moderate to severe upper limb deficits, at least six months post-stroke. They were randomly assigned to three groups: a robot-assisted therapy group (49 participants), a comparative intensive care group (50 participants) and a standard care group (28 participants).

Robot-assisted therapy was administered using In-Motion rehabilitation robots, which allow guided movements of the upper limb, providing visual and kinesthetic feedback to patients. Intensive comparative therapy was adapted to match robotic therapy in terms of duration and frequency of sessions but was based on traditional rehabilitation methods. The standard care group received treatments commonly available in Veterans Affairs medical centers, without a specific intervention dictated by the study. Study results indicated a significant benefit of intensive therapy over standard care at 12 weeks post-treatment, with a mean improvement of 4.0 points in the Fugl-Meyer score, which assesses sensorimotor recovery (95% CI = 1.3-6.7; P = .005). However, at 36 weeks post-treatment, the observed benefit was attenuated, with a mean difference of 3.4 points (95% CI = -0.02 to 6.9; P = .05). Subgroup analyses revealed that younger patients and those whose time since stroke was shorter showed greater improvements both immediately and in the long term, highlighting the importance of personalized treatment based on each patient's individual characteristics.

Since stroke is the leading cause of motor disability most studies analyze the efficacy of post-stroke robot-assisted therapy. In a meticulous evaluation of data from 44 randomized controlled trials involving a total of 1362 participants, modest but significant improvements in motor function and muscle strength of the affected arm were observed with no serious adverse events reported, indicating the safety of this therapeutic modality. The studies reviewed offered a variety of interventions, including the use of specialized robotic systems for shoulder and elbow rehabilitation,

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as well as elbow and wrist devices, reflecting the technological diversity in the field of robotic rehabilitation. Improvements in motor control, as assessed by mean changes of approximately 2 points on the Fugl-Meyer arm scale, and increased muscle strength highlighted the specific effectiveness of the targeted joint interventions. However, these effects did not generalize to global upper limb capacity or to the performance of basic daily activities, highlighting the need for more holistic and personalized therapeutic approaches. Despite the observed improvements, the analysis revealed that the effects of robotic therapy in the initial weeks after a stroke remain unclear, pointing to a gap in the literature and in the understanding of the optimal time to initiate this form of therapy. Additionally, the interactions between patient age, time since stroke and type of robotic intervention suggest that the effectiveness of therapy may vary depending on individual patient characteristics, highlighting the importance of careful patient selection and personalization of therapy.

In recent research on gait rehabilitation after stroke, Chung BP's 2017 study included a total of 41 participants, 14 of whom were assigned to the group receiving robotic-assisted gait therapy (RAGT) and 27 to the control group, which received standard physical therapy. Results showed that the group receiving robotic-assisted therapy benefited to a greater extent in terms of ambulation, motor activity and balance, suggesting additional benefits of robotic-assisted therapy.

In 2018, Erbil and collaborators explored the impact of combining robotic-assisted training with conventional physical therapy, involving 48 participants, with 32 in the robot-assisted group and 16 in the control groups. The study concluded that the combined management provided more substantial benefits for patients with chronic hemiplegia, indicating the effectiveness of adding robotic therapy to rehabilitation plans.

Li et al. in 2021 compared the effects of using exoskeletal robots for gait training with traditional therapy in a study involving 130 participants split between a group that used robotic technology for gait training and a control group that received traditional gait training. No significant differences were found between the groups in terms of improved locomotion skills, suggesting similar effectiveness between robotic and traditional therapy.

The study by Pohl et al. included 155 patients who were divided into two groups: one received locomotor training and physical therapy, and the other only physical therapy. The group that benefited from both interventions showed significant improvements in walking ability, highlighting the importance of intensive and repetitive training.

Meta-analysis conducted by Mehrholz et al. in 2020, which included 62 trials with a total of 2440 individuals, evaluated the effects of electromechanically assisted gait training in combination with physical therapy. The findings indicate that this type of training, in combination with physical therapy, increased the likelihood of unassisted walking compared to traditional methods, illustrating the potential benefits of robotic technology in motor rehabilitation. The analyzed data highlights the potential of robotic systems in improving functional recovery of patients with motor disabilities, highlighting the significant progress made in the field of robotic rehabilitation. The mentioned clinical studies show measurable improvements in upper limb motor function, validating the effectiveness of robot-assisted therapy in the rehabilitation context. These results can be used to argue the importance of further research and development in the field of robotic rehabilitation.

4.1. Full Brain-Computer Interface (BCI) Integration

Although there are advances in the development of brain-computer interfaces for controlling robotic devices, their full and effective implementation in motor rehabilitation is still limited.

What should be done: Further research to improve the accuracy and reliability of BCIs, the development of more effective non-invasive methods and their integration into complex robotic systems for rehabilitation.

4.2. Personalizing Robotic Therapies

Most current systems offer standardized rehabilitation programs, without taking full account of individual patient needs.

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What should be done: Develop advanced algorithms for personalizing treatments that adapt in real time to each patient's progress and responses, using artificial intelligence and machine learning.

4.3. Accessibility and Costs of Robotic Systems

The high cost of robotic devices and lack of accessibility in many regions limit their widespread use.

What should be done: Conduct research to reduce production costs, develop sustainable economic models and take initiatives to subsidize the purchase of robotic equipment in healthcare institutions.

4.4. Integration into Clinical Practice

The effective integration of robotic technologies into the daily routine of clinics and hospitals is often hampered by a lack of adequate infrastructure and staff training.

What should be done: Develop comprehensive training programs for therapists and medical staff, invest in clinical infrastructure and promote partnerships between technology developers and medical institutions.

4.5. Long-term Evaluation of the Effectiveness of Robotic Therapies

Existing studies often focus on short-term outcomes without evaluating the long-term effectiveness of robotic-assisted rehabilitation.

What should be done: Implement long-term clinical trials that monitor and evaluate the impact of robotic therapies on patients' functional recovery as well as their quality of life.

4.6. Social and Cultural Acceptance of Robotic Technologies

Cultural and social resistance to the use of robotic technology can limit the widespread adoption of these solutions.

What should be done: Awareness and education campaigns to demystify robotic technologies and highlight their benefits, involving communities in the development and implementation process of these technologies.

5. Conclusions

The review of advances and challenges in the field of rehabilitation and robotic care brings to the fore the huge potential of emerging technologies in improving the lives of patients with physical disabilities. Results from selected studies underscore the effectiveness of robotic systems in improving motor function of the upper and lower limbs, offering new hope for recovery. However, we find that although there are measurable improvements in motor control and muscle strength, the direct applicability of these improvements in patients' daily activities and autonomy remains a challenge.

Studies, such as those mentioned in the article, illustrate significant technological advances, but also the critical need for additional research to address gaps in literature.

Although robotic systems show significant benefits in improving motor function, further research is essential to maximize the effectiveness of these technologies in clinical practice. It is imperative that greater attention is paid to personalizing therapy, considering the individual specificities of each patient. It is also vital to address the challenges of cost, staff training and adapting infrastructures to facilitate the widespread integration of robotic solutions in motor rehabilitation.

In addition to the functional improvements observed because of robotic therapy, it is essential to recognize and harness the potential of these technologies to improve the psychological state of patients. Tailored approaches that consider the individual needs of patients, together with innovative solutions to overcome cost and accessibility barriers, are key to the wider integration of robotic rehabilitation into clinical practice. By expanding research and development in this area, we have the opportunity to profoundly transform the motor recovery and quality of life of patients with physical disabilities.

Even if the increase in scores assessing the effectiveness of robotic therapy is not yet at major differences from classical therapy, some advantages remain unbeatable: the reduction of staff required, the possibility of telemedicine and continuous treatments without the need to travel or staff changes, and of course the precision with which robotic systems can measure and generate in particular the specific torques and velocities of movements in physical rehabilitation exercises.

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