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Innovations in Pediatric Rehabilitation Therapies: Using Biomedical Technology to Improve Mobility in Children with Neuromuscular Disabilities

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ABSTRACT
Neuromuscular disabilities affect children's mobility, limiting their physical and social development. Innovations in biomedical technology, such as exoskeletons and neuromuscular stimulation devices, are revolutionizing pediatric rehabilitation therapies. This article explores the impact of these technologies on the mobility of children with neuromuscular disabilities. Through an analysis of recent studies, the advantages and limitations of these technological therapies are examined, highlighting the advances in the design and application of biomedical devices and their effects on the quality of life of patients. The results suggest that biomedical technology can significantly improve motor functionality in this population, although longitudinal studies are still required.

Keywords: pediatric rehabilitation, biomedical technology, mobility, neuromuscular disabilities, exoskeletons, neuromuscular stimulation.

INTRODUCTION

Neuromuscular disabilities in the pediatric population constitute a significant challenge for both patients and health professionals, as they negatively impact motor development, independence, and ultimately the quality of life of affected children and their families (Huang et al., 2021). These conditions, which include diseases such as cerebral palsy, muscular dystrophy, and spina bifida, affect the muscles and nerves responsible for movement and coordination, leading to a progressive deterioration in motor function (Olivieri et al., 2023). In response to these limitations, rehabilitation therapies have evolved from conventional methods to approaches that integrate advanced technology to promote better clinical outcomes and a higher level of autonomy in patients (Cao & Wilson, 2022).

With the advancement of biomedical technology, innovative devices have been developed, such as exoskeletons and functional neuromuscular stimulation (NFS) systems, which offer new opportunities to improve mobility in children with neuromuscular disabilities (Gates et al., 2023). These devices not only seek to restore the ability to walk and improve motor control, but also to reduce the risk of musculoskeletal deformities and contractures, common problems in this pediatric population (Zhang et al., 2022). Exoskeletons, for example, act as an external structural support that, by integrating motors or assistance mechanisms, allows children to walk in an assisted manner and perform movements that would otherwise be difficult or impossible (Lee & Choi, 2021). These devices have also been shown to be effective in improving posture and stability, factors that contribute to the child's psychomotor development and reduce dependence on conventional orthopedic aids (Martínez et al., 2020).

On the other hand, functional neuromuscular stimulation uses electrical impulses to activate paralyzed or weakened muscles, facilitating movement and improving muscle strength. This technique has shown positive effects in strengthening muscles and reducing spasticity, a common symptom in neuromuscular conditions such as cerebral palsy (Rodriguez & Lee, 2022). In addition, as it is a non-invasive technology, NFE is suitable for use in children, allowing early interventions that can influence neurophysiological development and brain plasticity, crucial factors to maximize the recovery of functions at an early age (Martínez et al., 2020).

Technological interventions in pediatric rehabilitation not only seek to improve motor outcomes, but also have an impact on the emotional and psychological well-being of patients. By allowing children to develop greater independence in their movements, these devices promote greater social interaction and better integration into school activities and daily life, fundamental aspects for their integral development (Thompson et al., 2023). In this sense, access to exoskeletons and NFE devices not only transforms the rehabilitation approach, but also contributes to reducing the stigma associated with disability, strengthening children's self-esteem and sense of competence (Cao & Wilson, 2022). However, access to these technologies remains limited in many contexts due to economic factors and the need for trained personnel to operate and supervise them (Smith et al., 2021).

In this context, the present article aims to explore innovations in biomedical technology applied to the rehabilitation of children with neuromuscular disabilities, with a focus on exoskeleton devices and functional neuromuscular stimulation. The most recent research will be analyzed in relation to their effectiveness, the challenges in their implementation and the impact they have on the mobility and quality of life of pediatric patients. The review of recent studies will make it possible to evaluate the progress of these technologies in the last decade and their role in the field of pediatric rehabilitation (Gates et al., 2023).

Theoretical Framework

Innovations in biomedical technology have transformed pediatric rehabilitation, especially in the area of neuromuscular disabilities. These conditions affect neuromuscular pathways and limit children's ability to move independently, which negatively impacts their physical, psychological, and social development (Olivieri et al., 2023). Among these innovations, exoskeletons and functional neuromuscular stimulation (NFS) stand out, devices that have shown efficacy in improving mobility and reducing the symptoms of spasticity and muscle weakness that characterize these disorders (Rodríguez & Lee, 2022).

Pediatric Exoskeletons

Exoskeletons are external structures that provide support and assistance to the movement of patients. In the pediatric setting, these devices are designed to fit into children's growing bodies, posing additional challenges in terms of design and effectiveness. Paediatric exoskeletons have been shown to be beneficial in improving gait and postural stability, providing a higher level of independence and reducing the need for care support (Cao & Wilson, 2022).

Below are the main benefits and limitations of pediatric exoskeletons reported in recent studies:

Benefits of Pediatric Exoskeletons	**Limitations of Pediatric Exoskeletons**
Improved gait and stability (Lee & Choi, 2021)	High cost of acquisition and maintenance (Thompson et al., 2023)
Reduced muscle spasticity (Zhang et al., 2022)	Need for specialized personnel for its use (Gates et al., 2023)
Increased autonomy and social integration (Martínez et al., 2020)	Limited accessibility in low-resource settings (Smith et al., 2021)

The design of these devices must take into account factors such as the child's growth, variability in muscle tone, and the need for constant adjustments to maximize the effectiveness of the treatment (Olivieri et al., 2023). In addition, exoskeletons offer psychological benefits, because by increasing children's autonomy, they also improve their self-esteem and allow them to participate in social and recreational activities, contributing to their integral development (Cao & Wilson, 2022).

Functional Neuromuscular Stimulation (NFS)

Functional neuromuscular stimulation is another technology that has shown positive results in pediatric rehabilitation, particularly in children with cerebral palsy and other conditions that affect motor function. NFS uses electrical impulses to activate weakened muscles, facilitating movements that could not otherwise be performed voluntarily. This technology helps reduce muscle atrophy, improve strength, and reduce spasticity in the affected limbs (Rodriguez & Lee, 2022).

Recent studies also highlight the impact of NFE on neuronal plasticity, a critical aspect in pediatric rehabilitation. Since children's brains are highly plastic, electrical stimulation can promote neuronal reorganization, promoting improvements in motor control and coordination (Huang et al., 2021). This is especially relevant for children, as early intervention with NFS can have long-lasting effects on motor function and quality of life.

Main Benefits of NFS in Pediatric Rehabilitation	**Effects**
Improved muscle strength (Martínez et al., 2020)	Reduced weakness in affected limbs
Reduction of spasticity (Zhang et al., 2022)	Decreased stiffness and improved range of motion
Promoting neural plasticity (Huang et al., 2021)	Increased neural reorganization and improved motor control

Integration of Biomedical Technology in Pediatric Rehabilitation

The incorporation of exoskeleton and NFE devices into pediatric rehabilitation programs presents new challenges and opportunities. On the one hand, the effectiveness of these technologies in improving motor function and promoting children's independence is a significant advance. However, the implementation of these technologies on a large scale faces economic challenges, due to the high costs of acquiring and maintaining these devices, and the need to train health personnel for their correct use (Thompson et al., 2023).

In addition, there is growing concern about the accessibility of these devices in developing countries, where health care resources are often limited (Gates et al., 2023). In this sense, it is essential that health policies consider financing and subsidy strategies to improve access to these technologies in vulnerable populations.

Challenges in the Implementation of Biomedical Technologies in Rehabilitation	Description
High cost of devices and maintenance (Thompson et al., 2023)	Limitation in implementation worldwide
Need for specialized training (Smith et al., 2021)	Requires staff with advanced technical knowledge
Limited accessibility in low-resource countries (Gates et al., 2023)	Increased vulnerability in disadvantaged contexts

Biomedical technology in pediatric rehabilitation has shown considerable potential to improve the mobility, autonomy, and social integration of children with neuromuscular disabilities. However, its effective implementation requires overcoming economic and logistical barriers, as well as having a health system that supports and facilitates access to these innovations.

Methodology

The present research is based on a systematic review of the recent scientific literature (2019-2024) on the use of biomedical technology in the pediatric rehabilitation of children with neuromuscular disabilities. We selected studies examining the effectiveness of exoskeletons and functional neuromuscular stimulation (NFS) devices in improving mobility and quality of life in this population. The methodology followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, ensuring a thorough and systematic review (Moher et al., 2019).

Inclusion and Exclusion Criteria

To ensure that only studies of high relevance and quality were included, the following inclusion and exclusion criteria were defined:

Inclusion Criteria	Exclusion Criteria
Studies published between 2019 and 2024	Studies published before 2019
Studies in English or Spanish	Studies in other languages
Studies evaluating exoskeletons and NFS in children	Studies with technologies other than exoskeletons and ENF
Clinical trials, systematic reviews, and meta-analyses	Case studies or studies with an uncontrolled observational design

These criteria were used to ensure the external validity of the results and minimize bias in study selection (Thompson et al., 2023).

Sources of Information

Broad-access academic databases, such as PubMed, Scopus, and Google Scholar, were consulted to ensure comprehensive coverage of the available literature. Specific keywords, such as "pediatric exoskeletons", "functional neuromuscular stimulation in children", "childhood neuromuscular rehabilitation" and "neuromuscular disabilities", were used together with Boolean operators to optimize the search (Rodríguez & Lee, 2022).

Database	Number of Studies Retrieved	Number of Studies Included
PubMed	135	45
Scopus	180	52
Google Scholar	210	35

Selection Process and Quality Assessment

The retrieved articles were evaluated in two phases. In the first phase, we reviewed titles and abstracts to rule out studies that clearly did not meet the inclusion criteria. In the second phase, a complete review of the text was carried out to assess the methodological quality and relevance of the content (Olivieri et al., 2023). To this end, the CASP (Critical Appraisal Skills Programme) assessment tool was used for clinical trials and systematic reviews, ensuring the quality of the selected studies (Gates et al., 2023).

Selection Stage	Number of Studies Evaluated	Selected Studies
Title and abstract review	525	132
Full text review	132	97

Data Extraction and Analysis

From each selected study, relevant data were extracted, such as study design, sample size, duration of intervention, type of biomedical technology used (exoskeletons or NFEs), and outcomes in terms of improved mobility and quality of life of children. Data extraction was done using a standardized spreadsheet to ensure uniformity in the process (Cao & Wilson, 2022).

For data analysis, we performed meta-analysis where possible, using fixed-effect or random-effect models, depending on the heterogeneity of the studies. In addition, the I^2 statistic was used to measure heterogeneity among the included studies (Martínez et al., 2020).

Variable Analyzed	Description
Study design	Design Type: Clinical Trial, Systematic Review
Samplesize	Total number of participants in each study
Durationoftheintervention	Duration in weeks or months
Typeoftechnology	Exoskeletons or functional neuromuscular stimulation
Mainresults	Changes in mobility, spasticity, and quality of life

Summary of Results

The results were grouped and analyzed according to the types of biomedical technology (exoskeletons and NFE) and their impacts on mobility, muscle strength, spasticity and quality of life. Each outcome was weighted according to study size and methodological quality to ensure the validity of the synthesis of findings (Smith et al., 2021).

Results

The systematic review and meta-analysis of recent studies (2019-2024) on the use of exoskeletons and functional neuromuscular stimulation (NFS) in the pediatric rehabilitation of children with neuromuscular disabilities provided promising results in terms of improved mobility, reduced spasticity, and increased functional independence.

Improving Mobility

In studies of exoskeleton interventions, data show a significant improvement in walking ability and physical endurance in children with neuromuscular disabilities. Zhang et al. (2022) reported a 40% increase in walking ability in children who wore exoskeletons for 12 weeks compared to those who followed conventional therapy. In addition, in a study conducted by Lee and Choi (2021), it was observed that the use of exoskeletons improved walking speed by 30% and stability by 25% in children with moderate cerebral palsy.

I am a student	Duration of the Intervention	Type of Improvement in Mobility	Increase (%)
Zhang et al. (2022)	12 weeks	Walking capacity	40%
Lee & Choi (2021)	8 weeks	Walking speed and stability	30% and 25%
Martínez et al. (2020)	6 months	Independence in mobility	35%

These results indicate that the use of exoskeletons in rehabilitation therapies not only increases mobility, but also allows children to participate in daily activities with less assistance, promoting their independence (Martínez et al., 2020).

Spasticity Reduction

Functional neuromuscular stimulation (NFS) has shown effective results in reducing muscle spasticity, a common symptom in children with neuromuscular disabilities, especially those with cerebral palsy. In a controlled clinical trial, Gates et al. (2023) observed that children who received NFS for 16 weeks had a 45% reduction in spasticity of the muscles of the lower limbs compared to groups that did not receive this intervention.

I am a student	Duration of the Intervention	Spasticity Reduction (%)
Gates et al. (2023)	16 weeks	45%
Olivieri et al. (2023)	10 weeks	38%
Rodriguez & Lee (2022)	8 weeks	32%

Reducing spasticity not only facilitates movement, but also reduces pain associated with muscle stiffness, which is crucial for improving the quality of life of pediatric patients (Olivieri et al., 2023).

Increased Muscle Strength

In addition to reducing spasticity, NFS has also been shown to be effective in increasing muscle strength in children with significant limb weakness. A study by Rodriguez and Lee (2022) showed that children who used NFE three times a week for 8 weeks experienced a 28% increase in leg strength compared to children who did not use NFE. This increase in muscle strength makes it easier to perform physical activities and reduces the need for external help for basic movements.

I am a student	Duration of the Intervention	Increase in Muscle Strength (%)
Rodriguez & Lee (2022)	8 weeks	28%
Lee & Choi (2021)	12 weeks	25%
Huang et al. (2021)	10 weeks	30%

Impact on Quality of Life and Independence

The studies reviewed also indicate that the use of exoskeletons and NFS in children with neuromuscular disabilities has a positive impact on their quality of life. The data suggest that children experience greater autonomy in their daily activities and an improvement in their self-esteem by being able to perform tasks with less dependence on their caregivers. Thompson et al. (2023) reported that 80% of parents of children who wore exoskeletons for 6 months observed an improvement in their children's quality of life, highlighting greater participation in social and school activities.

I am a student	Duration of the Intervention	Quality of Life Improvements (%)
Thompson et al. (2023)	6 months	80%
Gates et al. (2023)	4 months	75%
Cao & Wilson (2022)	3 months	70%

These findings underscore the importance of integrating biomedical technologies into pediatric rehabilitation, as they not only improve physical aspects of mobility, but also impact patients' emotional and social well-being.

Summary of Results

The data collected indicate that both exoskeletons and NFS are effective in improving mobility, reducing spasticity, and increasing muscle strength in children with neuromuscular disabilities. Exoskeletons were particularly effective in improving walking ability and independence, while NFS showed better results in reducing spasticity and strengthening muscle (Smith et al., 2021).

In conclusion, biomedical technology in pediatric rehabilitation offers multidimensional benefits for children with neuromuscular disabilities, improving not only physical function, but also quality of life and emotional well-being.

CONCLUSIONS

Advances in biomedical technology applied to pediatric rehabilitation, especially through the use of exoskeletons and functional neuromuscular stimulation (NFS), have shown significant potential to improve the quality of life of children with neuromuscular disabilities. The results reviewed in this study suggest that these technologies not only have a positive impact on physical aspects such as mobility, muscle strength, and the reduction of spasticity, but also promote children's autonomy and independence, facilitating their integration into daily activities and improving their emotional well-being (Zhang et al., 2022; Gates et al., 2023).

Exoskeletons stand out as an effective tool to improve walking ability and postural stability in children with neuromuscular conditions, allowing them to achieve levels of independence that could hardly be achieved with conventional therapies. In addition, exoskeletons not only help to develop strength and physical endurance, but also reinforce confidence in young patients, positively impacting their self-esteem and ability to socialize

(Martínez et al., 2020; Thompson et al., 2023). However, the high cost and need for trained personnel for the safe use of exoskeletons remain significant barriers to their widespread adoption (Thompson et al., 2023).

On the other hand, functional neuromuscular stimulation (NFS) has been shown to be particularly effective in reducing spasticity and strengthening specific muscles, which contributes to an improvement in motor control and a greater ability to perform basic activities without assistance. This approach is especially valuable in the treatment of children with cerebral palsy, where spasticity and muscle weakness often severely limit mobility and functionality (Rodriguez & Lee, 2022; Lee & Choi, 2021). In addition, NFE, by encouraging neural plasticity, offers long-term benefits, as repeated use of this technology can promote lasting changes in children's developing brains, thereby increasing the potential for recovery of motor functions (Huang et al., 2021).

Despite the obvious benefits, the economic and logistical challenges associated with these biomedical technologies represent a major obstacle to their large-scale implementation. In developing countries, where resources for specialized medical care are often limited, access to exoskeletons and NFE devices remains scarce (Gates et al., 2023). In this sense, it is crucial that health systems consider subsidy or financing strategies that allow children in low-resource settings to access these technologies, with the aim of reducing the gap in care and improving rehabilitation outcomes in vulnerable contexts (Smith et al., 2021).

Finally, it is important to note that although the studies reviewed provide promising evidence, additional research is needed to assess the long-term impact of exoskeletons and NFS on pediatric rehabilitation. Longitudinal studies exploring the sustained effects of these interventions will help determine whether the initial benefits are sustained over time and how they influence the overall development of children with neuromuscular disabilities (Olivieri et al., 2023). Further research is also needed to optimize the design and accessibility of these devices, so that they can be adapted to the specific needs of each child and context (Cao & Wilson, 2022).

In conclusion, the integration of biomedical technology into pediatric rehabilitation represents a significant step towards a more effective and inclusive approach in the treatment of neuromuscular disabilities in children. With the right support in terms of funding and training, these innovations have the potential to transform the lives of young patients, promoting a higher quality of life, autonomy, and social participation (Thompson et al., 2023; Gates et al., 2023).

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