

International Journal of Stem Cells and Medicine

Review Article

New Progress in Pediatric Rehabilitation Research

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Received Date: 31 March 2026; **Accepted Date:** 20 April 2026; **Published Date:** 27 April 2026

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Abstract

Objective: Pediatric rehabilitation is an interdisciplinary frontier of pediatrics and rehabilitation medicine with rapid technological advances. This paper systematically reviews key global progress in pediatric rehabilitation over the past three years, clarifies the application status and trends of cutting-edge technologies, and provides references for clinical practice, scientific research, and service system development.

Methods: Based on high-quality domestic and international literature and clinical studies from 2024 to 2026, we focused on five core diseases including cerebral palsy and autism spectrum disorder, and conducted classified integration and inductive analysis from multiple dimensions.

Results: In the past three years, breakthroughs have been achieved in precise assessment and targeted intervention in pediatric rehabilitation. Novel neuromodulation, digital rehabilitation, gene and regenerative medicine approaches have been gradually translated into clinical practice. Among them, the integration of brain-computer interface (BCI) and functional electrical stimulation (FES), virtual reality (VR)-based individualized rehabilitation, exoskeleton robot-mediated neural remodeling, non-invasive neuromodulation, and artificial intelligence (AI)-assisted BCI systems [3] have developed rapidly. Intervention efficacy, individualization level, and service accessibility have been significantly improved, and industrial policies and standards have been continuously improved.

Conclusion: Pediatric rehabilitation is transforming from traditional symptomatic intervention to a modern model featuring precision, intelligence, and biological repair, with multi-factor collaboration promoting disciplinary development. Future efforts should strengthen interdisciplinary integration, clinical translation, and grassroots promotion to improve service capacity and prognosis in children

Keywords: Pediatric rehabilitation, Neuromodulation, Biological intervention, Brain-computer interface, Functional electrical stimulation, Exoskeleton robot, Non-invasive neuromodulation, Digital intelligence, Precision rehabilitation.

Introduction

Neurodevelopmental disorders and congenital diseases in children seriously affect physical and mental health, reduce quality of life, hinder social adaptation, and exert profound impacts on long-term development and family life. Global

child health data show a rising incidence, making these conditions one of the leading causes of disability and impaired quality of life in children.

Traditional pediatric rehabilitation mainly relies on symptom-

atic interventions such as physical therapy, speech therapy, and occupational therapy. Although these approaches can partially improve functions, they are limited by long rehabilitation cycles, poor individualization, and unsatisfactory long-term outcomes, which can hardly meet the demands for high-quality rehabilitation.

In recent years, the deep integration of neuroscience, gene editing, AI, and regenerative medicine has revolutionized pediatric rehabilitation, shifting from empirical intervention to precision targeting, biological repair, and intelligent empowerment. Emerging neurorehabilitation technologies—including BCI-FES integration, VR individualized rehabilitation, exoskeleton robots for neural remodeling, non-invasive neuromodulation, and AI-assisted BCI systems [3]—are reshaping clinical pathways. From 2024 to 2026, numerous effective and practicable technologies have emerged globally, with some entering clinical translation, providing strong momentum for pediatric rehabilitation.

This paper systematically reviews rehabilitation progress for pediatric neurodevelopmental disorders and congenital diseases by disease category, elaborates mechanisms, clinical effects, and potentials of new technologies, and provides evidence for clinical optimization, research direction, and policy-making to promote precise, efficient, and personalized pediatric rehabilitation.

New Progress in Rehabilitation Research by Disease

Cerebral Palsy (CP)

Cerebral palsy is characterized by motor dysfunction, often accompanied by spasticity and impaired fine motor skills, representing a key focus in pediatric rehabilitation. Studies from 2024 to 2026 have focused on optimized motor rehabilitation, neuromodulation, and genetic mechanisms, forming a multi-dimensional intervention system.

Innovations in Motor Rehabilitation

The intermittent running plus strength training (PT³) protocol is effective in children aged 10–17 years with bilateral spastic cerebral palsy. Gait speed improves significantly after 2 months of intervention and maintains for 6 months, superior to traditional steady-state training [9]. Local vibration therapy (LVT) combined with upper limb training effectively improves hand function in children with spastic hemiplegia; after 12 weeks, fine motor scores increase and electromyographic spasticity indices decrease significantly [10]. Hydrotherapy reduces muscle tone via buoyancy and promotes gross and fine motor recovery, with better effects than conventional rehabilitation [11].

Applications of Exoskeleton Robots and BCI Technology

In gait rehabilitation, single-limb exoskeleton robots (e.g., Angele LiteStepper) significantly improve balance and gait

after 4 weeks of training in subacute stroke patients (extrapolated to pediatric CP) and activate the affected motor cortex to facilitate neural remodeling. For upper limb function, the 3D-printed TRIHFT objects developed by the University of Toronto [3], combined with a robotic arm, enhance grasping success rate and rehabilitation engagement. The remote BCI-FES system [3] developed by the University of Sheffield improves upper limb rehabilitation; in post-stroke patients, the FMA-UE score increases by an average of 3.83 points with a retention rate of 87.5%, supporting home rehabilitation for children with CP.

Integration of Neuromodulation and Intelligent Rehabilitation

Precise neuromodulation is a core breakthrough: repetitive transcranial magnetic stimulation (rTMS) targeting the motor cortex combined with transcranial direct current stimulation (tDCS) and real-time fNIRS monitoring improves motor recovery efficiency by over 30% [4]. VR immersive training simulates real scenarios, enhances compliance, and promotes motor and balance function recovery [5].

Genetic Mechanisms and Precision Screening

Whole-exome sequencing reveals genetic heterogeneity in Chinese children with CP and identifies associations between pathogenic loci and clinical phenotypes, providing a theoretical basis for early screening, individualized treatment, and genetic counseling [9].

Autism Spectrum Disorder (ASD)

ASD is characterized by social-communication deficits and repetitive behaviors. Rehabilitation has long been challenged by insufficient individualization and limited efficacy. From 2024 to 2026, the combination of biological intervention, neuromodulation, and digital rehabilitation has built a full-chain system of biological repair–behavioral intervention–intelligent empowerment.

Breakthroughs in Biological Intervention

Extracellular vesicle/exosome therapy has become a hotspot. Nasal or intravenous exosomes exert anti-inflammatory, synaptic repair, and gut–brain axis regulatory effects, improving motor and cognitive functions without immune rejection, showing scalable potential [1]. A systemic biological intervention combining 20 minutes of daily targeted exercise and gut microbiota regulation increases brain functional connectivity density by 3.2 times and improves connectivity by 43%, laying a physiological foundation for ASD rehabilitation [1].

Synergistic Neuromodulation and Digital Rehabilitation

rTMS/tDCS combined with language training precisely improves language clarity and social motivation [2]. EEG/fNIRS neurofeedback closed-loop training regulates θ/β rhythms and boosts speech training efficiency by 2.4 times. VR social

simulation improves emotion recognition and social interaction rate to 92.5% [2]. AI multi-modal assessment enables rapid classification and personalized intervention [2]. A visual–tactile multi-modal closed-loop system activates the mirror neuron network and enhances cortex–muscle coherence.

Home VR Rehabilitation and AI Dynamic Difficulty Adjustment

The RAPAEI smart glove (Juntendo University, Japan) integrating VR and occupational therapy significantly [3] improves activities of daily living in 62% of chronic stroke patients and is applicable for home-based ASD rehabilitation. The Belgian ROBiGAME system uses AI dynamic difficulty adjustment [3] (DDA) with a correlation of $r=0.84$ to the FMA-UE score, realizing individualized and high-engagement social training for children with ASD.

Developmental Language Disorder (DLD / Speech Disorder)

Developmental language disorder, including language delay and specific language impairment, severely impairs communication and social development. Research from 2024 to 2026 focuses on precise neuromodulation and intelligent assessment to achieve targeted and efficient language rehabilitation.

Precise Neuromodulation for Language Rehabilitation

rTMS targeting Broca's area combined with fNIRS monitoring improves language fluency by over 30% [6]. Anodal tDCS combined with language training enhances expression clarity by up to 40% [6]. The combined application provides non-invasive, highly targeted intervention.

Intelligent Assessment and Training Systems

AI multi-modal assessment integrating clinical scales, EEG/fNIRS, and deep learning achieves a classification accuracy of over 90% for DLD, resolving the subjectivity and inefficiency of traditional evaluation [6]. Neurofeedback closed-loop training combined with game-based rehabilitation improves fun and compliance while shortening the rehabilitation cycle [6].

Integrated VR and AI Dynamic Difficulty System

VR immersive scenarios simulate [3] real dialogues and stimulate communication motivation. The DDA module from the ROBiGAME system [3] automatically adjusts task difficulty based on real-time language performance, with a correlation of $r \geq 0.80$ between difficulty and language ability, supporting individualized high-engagement training.

Congenital Deafness (OTOF Mutation, etc.)

Congenital deafness severely impedes speech and cognitive development. Traditional intervention relies mainly on cochlear implants. In 2025, clinical breakthroughs in gene therapy enabled etiological cure, marking a milestone.

The world's first Phase I clinical trial of OTOF mutation gene therapy achieved success: binaural hearing was restored in 5 children, with significant improvements in speech expression and sound localization. The 12-month follow-up confirmed stable hearing, and auditory perception in noise was superior to that in cochlear implant users [11]. Published in *The New England Journal of Medicine*, this study supports a paradigm shift from replacement therapy to precision cure for hereditary deafness [11].

Non-invasive neuromodulation and multi-modal feedback assist auditory–speech integration training. Cerebellar intermittent theta burst stimulation (iTBS) combined with auditory training improves auditory attention and balance. Tongue stimulation combined with AI-BCI non-invasively modulates brain activity and enhances auditory–motor connectivity [3]. VR auditory scene training helps children adapt to sound recognition in noisy environments.

Intellectual Disability (ID)

The core rehabilitation goals for children with intellectual disabilities are to enhance cognitive abilities, sensory integration skills, and social adaptability. Research from 2024 to 2026 has focused on multimodal combined training to build a comprehensive rehabilitation intervention system.

The combined sensory integration training and cognitive training approach has demonstrated significant advantages in the rehabilitation of children with intellectual disabilities. Compared with conventional rehabilitation interventions, children who received this combined program showed marked improvements in sensory integration scores, cognitive level scores, and activities of daily living scores [7]. By integrating sensory integration exercises with cognitive training such as thinking and memory, this program comprehensively supports the development of social adaptability in affected children, offering an efficient and feasible pathway for long-term rehabilitation [7].

On this basis, emerging technologies have further enhanced the individualization and engagement of interventions. Home-based VR rehabilitation systems [3] (e.g., RAPAEI smart gloves) are used for training daily living skills in children with intellectual disabilities. AI-driven dynamic difficulty adjustment (DDA) systems [3] can automatically modify training difficulty based on the child's real-time cognitive performance, ensuring a balance between challenge and feasibility, thereby maintaining high engagement. Closed-loop multimodal feedback (visual + tactile) training activates mirror neuron networks, enhances corticomuscular coherence, and improves motor imitation and social responsiveness in children with intellectual disabilities.

Policy and Implementation Support (2026)

To promote inclusive application of pediatric rehabilitation achievements, China issued a medical insurance settlement optimization plan in 2026, covering six pediatric rehabilita-

tion categories (including CP, ASD, DLD) under per diem payment, replacing the traditional fee-for-service model[8]. This policy eases the economic burden, encourages service optimization, improves resource efficiency, and supports the popularization of advanced technologies [8].

At the industry level, the market deployment of emerging neural rehabilitation technologies is accelerating. China's Sichuan Province has mapped out a development pathway for the invasive brain computer interface (BCI) industry, aiming to perform 3,000 invasive BCI surgeries annually by 2030, with a target of serving 20,000 users. The global BCI market is expected to grow rapidly, with non invasive devices becoming more widespread; demand driven technological innovation is on the rise. In addition, new solutions are emerging in the field of non invasive neuromodulation. For example, lingual stimulation combined with an AI BCI system (developed by a subsidiary of Helius Medical) can non invasively modulate brain activity and improve motor function. Intermittent theta burst stimulation (iTBS) of the cerebellum combined with physical therapy has been shown to significantly improve balance and motor ability in stroke patients [3]. These technologies are gradually being extended to pediatric rehabilitation.

Summary and Outlook

Between 2024 and 2026, the field of pediatric rehabilitation has achieved systematic breakthroughs in areas such as neuromodulation, biological interventions, digital intelligence, exoskeleton robots, and precision rehabilitation. Across various conditions, a complete development chain of "technological breakthrough – clinical validation – policy support" has been established. Rehabilitation for cerebral palsy has realized deep integration of motor rehabilitation and neuromodulation; ASD rehabilitation has broken through traditional bottlenecks through the combination of biological interventions and digital technologies; rehabilitation for language development disorders has become more precise and efficient; congenital deafness has witnessed a historic breakthrough with gene therapy; and rehabilitation for intellectual disability has developed a multi-dimensional, integrated training system. Meanwhile, innovative technologies such as BCI-FES remote systems, AI-assisted personalized training, and lingual stimulation have provided more diverse options for pediatric rehabilitation.

Looking ahead, the field needs to further promote multi-center clinical validation and expand the clinical application of cutting-edge technologies; accelerate the development of technical standardization to unify intervention protocols and evaluation criteria; continue to deepen health insurance coverage and optimize the allocation of rehabilitation service

resources; and strengthen collaboration across medical, educational, and research sectors to facilitate the translation of basic research findings into clinical practice. These efforts will enable more children to benefit from advanced rehabilitation technologies and support the high-quality development of pediatric rehabilitation.

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