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Review Article

Contemporary, Novel and Modern Approaches in the Neurorehabilitation of Cerebral Palsy: A Narrative Review

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Abstract

Background: Cerebral palsy (CP) is a non-progressive neurodevelopmental disorder characterized by motor, postural, and functional deficits following damage to the developing brain [1]. It has a profound effect on motor function, independence and quality of life. Neurorehabilitation now emphasizes neuroplasticity-based, task-specific, and technology-assisted approaches to improve functional recovery [2].

Objective: This narrative review aims to evaluate the evidence regarding contemporary approaches such as Constraint-Induced Movement Therapy (CIMT), Neurodevelopmental Therapy (NDT), Modern approaches such as Robotic-Assisted Gait Training (RAGT), Virtual Reality (VR), novel approaches such as Dynamic Intensive Therapy (DIT), Action Observation Therapy (AOT) and Motor Imagery (MI) techniques.

Search Strategy: A narrative review of literature published between 2010 and 2025 was conducted using PubMed, Google Scholar, Ovid, and Embase databases. Randomized controlled trials, systematic reviews, meta-analyses, and clinically relevant studies on neurorehabilitation in cerebral palsy were selected based on type of intervention, patient characteristics and clinical outcomes.

Result: A total of 27 studies were included. Overall, the findings indicate that contemporary, modern and novel neurorehabilitation approaches are effective in individuals with cerebral palsy, with each intervention demonstrating benefits in different ways.

Conclusion: Available evidence suggests that CIMT and RAGT are highly effective in enhancing upper limb function and gait performance, respectively. DIT, VR, AOT, and MI demonstrated promising effects on motor learning, patient engagement and neuroplasticity. However, variability in treatment protocols and limited long-term evidence indicate the need for further high- quality research [3-7].

Keywords: Cerebral palsy, neurorehabilitation, constraint-induced movement therapy, robotic-assisted gait training, motor imagery, action observation therapy, virtual reality

Introduction

Cerebral palsy (CP) is an umbrella term for a group of non-progressive, permanent neurological conditions that mainly affect posture, motor function, and movement, resulting from abnormalities in the developing brain of a fetus or infant. It continues to be a major cause of childhood disability, affecting approximately 2-3 children per 1000 live births [1,8]. The clinical presentation of CP varies depending on the location and severity of the brain lesion and may include spasticity, muscle weakness, coordination difficulties, abnormal reflexes, and limitations in activities of daily living [1,8].

Traditionally, treatment approaches for cerebral palsy have focused on passive interventions such as stretching, positioning, and reflex inhibition [9,10]. While these techniques helped to prevent joint stiffness and contractures, they had limited benefits in improving function. As our understanding of the brain has improved, neuroplasticity has emerged as a key principle in neurorehabilitation [2,4]. Neuroplasticity refers to the ability of the brain to reorganize its structure and function in response to training, experience, and environmental stimulation. Recent evidence suggests that individuals with CP achieve better functional outcomes through intensive, goal-directed, and activity-based rehabilitation approaches that encourage active patient participation [11]. As a result, current rehabilitation approaches emphasize evidence-based, activity-oriented and technology-based interventions. Several innovative rehabilitation approaches based on these principles include the following Constraint-Induced Movement Therapy, Neurodevelopmental Therapy, Robotic-Assisted Gait Training, Dynamic Intensive Therapy, Action Observation Therapy (AOT), Motor Imagery and Virtual Reality rehabilitation. Although these approaches vary in their mechanisms and methods of application, they all have a common goal of improving motor function, improving participation and quality of life in individuals with cerebral palsy [3-5,7,9].

This narrative review discusses these contemporary rehabilitation strategies with emphasis on their underlying principles, clinical application, target population, and evidence regarding their effectiveness.

Methodology

This narrative review was conducted to evaluate contemporary, modern, and emerging neurorehabilitation approaches used in the management of cerebral palsy. Electronic databases including PubMed, Google Scholar, Ovid, and Embase were searched for relevant literature published between January 2010 and October 2025.The search strategy included keywords such as "cerebral palsy," "neurorehabilitation," "constraint-induced movement therapy," "robot-assisted gait training," "virtual reality rehabilitation," "motor imagery," and "action observation therapy," combined using Boolean operators (AND, OR) to identify relevant studies.

Randomized controlled trials, systematic reviews, meta-analyses, and clinically relevant studies focusing on neurorehabilitation interventions in cerebral palsy were considered for inclusion. Studies unrelated to cerebral palsy rehabilitation, non-neurological studies, conference abstracts, and articles without accessible full text were excluded.

A total of 74 articles were initially identified through database searching. After removal of duplicates and exclusion of unrelated or non-full-text articles, a total of 27 studies were included in this final review based on their relevance to emerging and evidence-based neurorehabilitation approaches in cerebral palsy. The selected studies were analysed based on intervention type, study design, participant characteristics, and reported clinical outcomes, including motor function, gait, balance, coordination, and functional independence. Particular emphasis was placed on interventions aimed at improving functional recovery, movement performance, and rehabilitation outcomes in children with cerebral palsy.

Intervention

Constraint-induced movement therapy (CIMT)

Constraint-Induced Movement Therapy is a widely recognized rehabilitation approach used to improve upper limb function in children with hemiplegic cerebral palsy. The approach is based on the concept of "learned non-use", in which reduced use of the affected limb results in further disuse and decreased cortical representation [3,12]. CIMT promotes the use of the affected limb by restricting the sound limb by using mitts, slings, or casts during therapeutic activities. CIMT is based on experience-dependent neuroplasticity, where repetitive task practice strengthens neural connections and enhances cortical reorganization. CIMT protocols commonly focus on functional tasks such as reaching, grasping, object manipulation, eating, and dressing [3,12,13]. There is robust research evidence on the effectiveness of CIMT, including many randomized controlled trials and reviews [13]. Several studies demonstrated improvements in upper limb function, bimanual coordination, and independence in activities of daily living following CIMT interventions [3,12,13]. However, CIMT may require high-intensity training and prolonged therapy duration, which can affect patient compliance and accessibility [13,27].

Neurodevelopmental therapy (NDT)

Neurodevelopmental Therapy, also known as the Bobath approach, is a well-established rehabilitation approach used in the management of cerebral palsy [9,10]. It is based on the principles of facilitating normal movement patterns while inhibiting abnormal postures and reflex activity through therapeutic handling techniques [11]. The fundamental concept of NDT is that abnormal muscle tone and impaired postural control interfere with normal movement patterns. Through appropriate sensory cues and postural alignment, therapists aim to facilitate normal motor responses and improve functional movement [6]. NDT primarily focuses on postural control, alignment and movement patterns via manual facilitation techniques. NDT has broad clinical application and can be used in various types of cerebral palsy, including spastic, dyskinetic, and ataxic forms, across different age groups, including early intervention programs. NDT is often combined with other rehabilitation interventions as part of a multidisciplinary treatment approach.

Robotic-assisted gait training (RAGT)

Robotic-Assisted Gait Training is an advanced neurorehabilitation approach that provides repetitive and controlled gait training for individuals with cerebral palsy [4]. It involves the use of robotic systems, such as treadmill-mounted exoskeleton devices, to facilitate controlled walking patterns [14]. RAGT enables intensive, repetitive, and task-specific gait training by providing controlled movement patterns with adjustable parameters such as speed, step length, and body-weight support. These features contribute to motor learning and functional recovery by promoting repetitive practice and neuroplastic adaptation [4,15]. Randomized controlled trials and systematic reviews support the use of RAGT for improving gait speed, endurance, walking symmetry, and functional mobility in individuals with cerebral palsy [14-16]. Better outcomes are generally observed in individuals receiving intensive and longer-duration training programs. However, RAGT has certain limitations, including high equipment costs, limited availability in clinical settings, and the requirement for skilled professionals [17]. Despite these limitations, RAGT continues to emerge as a promising intervention for improving walking ability in individuals with cerebral palsy.

Dynamic intensive therapy (DIT)

Dynamic Intensive Therapy (DIT), also known as intensive therapy or suit-based therapy, is a high-frequency, high-intensity rehabilitation approach that aims at improving motor function in individuals with cerebral palsy. It is based on the principle that intensive and repetitive practice may enhance neuroplasticity in the developing brain [7,18]. DIT emphasizes repetitive functional movements, task-specific training, and active patient participation. Some approaches involve the use of therapeutic suits, such as the Thera Suit or Adeli Suit, to provide external supports, enhance proprioceptive input and improve postural alignment during therapeutic activities [19]. The intervention commonly includes strengthening, balance training, gait practice, and functional task performance [18]. This approach is particularly suitable for children with moderate levels of cerebral palsy who are able to actively participate in intensive training sessions. However, DIT has certain limitations, including the lack of standardized treatment protocols and variability in clinical outcomes across studies [7]. In Addition, the effectiveness of DIT often depends on high patient motivation and significant therapist involvement.

Despite these challenges, DIT remains a promising intervention because of its strong emphasis on intensive practice and functional rehabilitation [19].

Action observation therapy (AOT)

Action Observation Therapy is an emerging neurorehabilitation technique that utilizes the mirror neuron system, which is activated during both observation and performance of goal-directed movements [6,20]. This mechanism plays a vital role in motor learning and cortical reorganization. In AOT, patients observe specific motor tasks such as reaching and grasping movements, followed by active imitation of the observed actions [20]. This process helps stimulate the motor cortex and movement execution. AOT is particularly beneficial for children with impaired motor planning and individuals who have difficulty in initiating voluntary movements. It is often combined with conventional physiotherapy to enhance treatment outcomes. One of the major advantages of AOT is that it is simple, cost-effective, and easy to implement in clinical and home settings, and it does not require advanced equipment.

Motor imagery (MI)

Motor Imagery is a cognitive process in which an individual mentally rehearses a movement without actually performing it [21]. It activates neural pathways similar to those involved in actual movement, and it may facilitate motor learning and improve cortical connectivity. MI stimulates several motor cortical areas, including primary motor cortex, premotor cortex and supplementary motor area. This neural activation promotes synaptic plasticity and improves motor planning .MI is particularly beneficial for individuals with limited physical ability and those unable to perform active movements because of weakness or spasticity. It is often used as an adjunct to conventional physiotherapy to enhance overall rehabilitation outcomes. Evidence suggests that MI may improve the motor planning, coordination and functional performance, especially when combined with active physical training [21].

Virtual reality (VR) rehabilitation

Virtual Reality is a technology-assisted rehabilitation approach that uses computer-generated simulations to perform functional activities in an interactive environment [5]. It enhances patient motivation and engagement through immersive therapeutic experiences [22]. VR-based rehabilitation provides real-time visual and auditory feedback, along with task-specific and repetitive practice. These features contribute to motor learning, patient participation and neuroplastic adaptation. VR is particularly effective in children with cerebral palsy because of its game-based environment, high levels of engagement and improved treatment compliance [23]. VR rehabilitation is commonly used to improve balance and coordination, upper limb function, and functional mobility. Several studies have demonstrated improvements in motor function, balance and coordination following VR-based interventions in individuals with cerebral palsy. In addition, VR provides a safe and controlled rehabilitation environment and allows individualized treatment programs. However, certain limitations exist, including the need for technological resources and limited accessibility in low- resource clinical settings [24]. Despite these limitations, VR continues to gain importance as an innovative and effective rehabilitation tool in cerebral palsy management [5].

Author and Year	Study Design	Intervention	Sample Characteristics	Main Findings
Bailes AF., *et al.* 2010	Intensive therapy study	Suit-wear intensive therapy	Children with cerebral palsy: ambulatory participants with motor impairments.	Improved gross motor function following intensive suit-based therapy.
Buccino., *et al.* 2012	Pilot study	Action observation therapy	Children with cerebral palsy with upper limb motor impairment.	AOT improved upper limb motor function and functional activity performance in children with cerebral palsy
DeLuca., *et al.* 2012	Clinical intervention study	Constraint-Induced Movement Therapy (CIMT)	Young children with cerebral palsy and upper limb impairment.	Children tolerated therapy dosage well and showed functional improvement.
Dewar., *et al.* 2015	Systematic review	Exercise interventions for postural control	Children with cerebral palsy with postural impairment.	Moderate evidence supports exercise interventions for improving postural control.
Jung., *et al.* 2018	Case series	Virtual Reality training using Xbox Kinect	Children with spastic cerebral palsy with balance impairment.	Improvement noted in balance and physical functioning after VR training.
Sah., *et al.* 2019	Randomized clinical trial	Task-oriented activities based on Neurodevelopmental Therapy (NDT)	Children with cerebral palsy with trunk control and balance impairment.	Improved trunk control, balance, and gross motor function.

Hoare., *et al*. 2019	Randomized controlled trial	Constraint-Induced Movement Therapy (CIMT)	Children with unilateral cerebral palsy with upper limb impairment.	CIMT showed better upper limb outcomes compared to low-dose therapy.
Karadag-Saygi., *et al*. 2019	Systematic review	Suit therapies	Children with cerebral palsy with motor and postural impairment.	Intensive task-specific suit therapy showed promising results.
Souto., *et al*. 2020	Cross sectional study	Motor imagery	Children with cerebral palsy and typically developing children.	Children with CP demonstrated motor imagery ability, but performance was slower and less accurate than typically developing children.
Vitrikas., *et al*. 2020	Review article	Overview of cerebral palsy management.	Children with cerebral palsy.	Discussed clinical presentation, diagnosis, and multidisciplinary management approaches in CP.
Pool., *et al*. 2021	Clinical intervention study	Robotic-Assisted Gait Training (RAGT)	Children with cerebral palsy with gait impairment.	Participants completed intervention safely with functional gait improvement.
Ramey., *et al*. 2021	Randomized trial	Constraint-Induced Movement Therapy (CIMT)	Children with unilateral cerebral palsy	High-dose CIMT produced greater improvement than moderate-dose therapy
Montoro-Cárdenas., *et al*. 2021	Systematic review and meta-analysis	Nintendo Wii Balance Board therapy	Children with cerebral palsy with balance impairment	Positive effects observed on dynamic balance
Belizón-Bravo., *et al*. 2021	Systematic review	Dynamic suit orthoses	Children with cerebral palsy with postural and gait impairment	Improved gait, balance, and functional outcomes
Moll., *et al*. 2022	Randomized controlled trial	Robot-Assisted Gait Training	Pediatric patients with cerebral palsy with gait impairment	Improvement observed in walking speed and gait performance
Cortés-Pérez., *et al*. 2022	Systematic review and meta-analysis	Robot-Assisted Gait Therapy	Children with cerebral palsy with gait impairment.	RAGT demonstrated better post-intervention outcomes than conventional therapy.
Ungureanu., *et al*. 2022	Pilot study	Bobath and Vojta methods	Children with cerebral palsy with motor impairment.	Improvement in symmetry and postural facilitation was observed.
Volpini., *et al*. 2022	Systematic review and meta-analysis	Assisted robotic gait training	Individuals with cerebral palsy with gait impairment.	Walking distance improved significantly following RAGT.
Te Velde., *et al*. 2022	Meta-analysis	Neurodevelopmental Therapy (NDT)	Children with cerebral palsy with motor impairment.	Moderate effect favoring activity-based rehabilitation approaches.

Khanna., *et al*. 2023	Literature review	Neurodevelopmental treatment	Children with cerebral palsy with motor impairment.	Further large-scale studies are recommended to confirm effectiveness.
Klobucká., *et al*. 2023	Cost-effectiveness analysis	Robotic-Assisted Gait Training (RAGT)	Children with cerebral palsy with motor impairment	RAGT was effective but associated with high treatment cost.
Julien., *et al*. 2024	Clinical intervention study	Robotic-Assisted Gait Training (RAGT)	Children with cerebral palsy with gait impairment.	Significant improvement observed in gait performance.
Ziab., *et al*. 2024	Double-blinded randomized controlled trial	Overground gait training compared with balance-specific and conventional training	Children with cerebral palsy with gait and balance impairment	Improvement observed in GMFM scores and goal attainment scales.
Takes., *et al*. 2025	Randomized comparative study	Robot-assisted gait training	Children with cerebral palsy with gait impairment.	Combined conventional therapy and RAGT showed functional gait improvement.
Martin-Moreno., *et al*. 2025	Systematic review and meta-analysis of follow-ups	Constraint-induced movement therapy and bimanual training	Children with cerebral palsy with upper limb impairment.	Improved upper limb function: further long-term studies needed.
Cortes-Perez., *et al*. 2025	Systematic review and meta-analysis	Dual task training interventions	Individuals with cerebral palsy with balance and walking	It improved postural balance and walking speed.
Perez-Carcamo., *et al*. 2025	Systematic review and meta-analysis	Non-immersive virtual reality rehabilitation	Children with cerebral palsy with gross motor and balance impairment.	VR rehabilitation improved gross motor function, balance, and functional independence.

Table 1: Summary of contemporary, novel, and modern neurorehabilitation approaches in cerebral palsy.

Discussion

This narrative review outlines current trends in neurorehabilitation for cerebral palsy, highlighting a shift from conventional passive treatment to more active, intensive, and neuroplastic-based approaches [2,4]. Neuroplasticity refers to the ability of the brain to reorganize neural pathways in response to repeated practice, motor learning, and environmental stimulation [2]. Contemporary rehabilitation approaches in cerebral palsy are increasingly designed to utilize neuroplastic mechanisms through repetitive, task-specific, and intensive training, thereby improving motor control and functional independence. This review highlights the variable effectiveness of different types of rehabilitation approaches based on their mechanisms and implementation. Although all interventions demonstrated beneficial effects, their effectiveness varied depending on treatment goals and patient characteristics. Constraint-Induced Movement Therapy showed stronger evidence for improving upper limb function [12], whereas Robotic-Assisted Gait Training was more effective for improving gait symmetry, walking endurance, and mobility outcomes [16]. Neurodevelopmental Therapy remains widely used in clinical practice, however, recent evidence suggests that task-oriented and intensive approaches may produce greater functional improvements in some children with cerebral palsy [10]. Virtual Reality rehabilitation also plays a role by enhancing engagement and compliance through interactive and motivating environments [24]. The provision of real-time feedback improves motor learning and function. However, interventions such as robotic-assisted therapy and virtual reality rehabilitation may have limited accessibility in low-resource clinical settings because of high equipment costs, the need for specialized training, and limited technological availability. In contrast, approaches such as CIMT and task-oriented therapy are comparatively more feasible and cost-effective for broader clinical implementation. The selection of rehabilitation strategies should be individualized according to the severity of impairment, functional goals, age, cognitive status, and availability of rehabilitation resources.

Novel interventions, such as Dynamic Intensive Therapy, Action Observation Therapy, and Motor Imagery have shown encouraging outcomes by promoting motor learning, cortical activation and functional outcomes [19-21]. These approaches demonstrate the importance of integrating cognitive and physical components of rehabilitation for better results.

Limitations

Although there is increasing evidence supporting contemporary neurorehabilitation strategies to improve motor function in cerebral palsy, several limitations remain. Few studies assessed new therapeutic interventions such as Motor Imagery and Action Observation Therapy, limiting the evidence. Lack of treatment protocols for each intervention leads to inconsistencies in clinical effects [7]. Many studies have small sample sizes, which could influence the reliability and generalizability of the results [19]. Differences in the duration, intensity and characteristics of the patient populations make it challenging to develop standardized clinical recommendations. Additionally, variability in intervention intensity, duration, outcome measures, and participant characteristics across studies limits direct comparisons between rehabilitation approaches. Another limitation was the use of different outcome measures across the included studies. Various tools were used to assess gait, balance, motor function, and functional independence, this heterogeneity in assessment tools made comparison of intervention effectiveness across studies more challenging.

Conclusion

The present review highlights the recent shift in the rehabilitation of cerebral palsy toward neuroplasticity-driven, task-specific, and intensive therapies [2]. The most robust evidence for enhancing upper limb function and walking ability comes from Constraint-Induced Movement Therapy and Robotic-Assisted Gait Training, respectively. Novel approaches such as Action Observation Therapy, Motor Imagery, and Virtual Reality have potential to improve motor learning, enhance cortical activation, and increase engagement, but more research is needed to determine their long-term efficacy [20,21,24,25]. Future studies should focus on long-term follow-up, standardized treatment protocols, and larger multicenter trials to better understand the sustainability of therapeutic outcomes across cerebral palsy rehabilitation approaches [26,27].

The results suggest that repetition, intensity and active engagement are critical elements to successful rehabilitation interventions. In summary, a multimodal, personalized approach is essential in the rehabilitation of individuals with cerebral palsy. Additional studies are needed to establish protocols, and assess long-term outcomes. Although these approaches differ in their mechanisms and methods of application, these interventions collectively aim to enhance motor function, promote participation, and improve the quality of life in individuals with cerebral palsy [4].

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