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# Effectiveness of Rehabilitation Interventions in Children with Brachial Plexus Birth Injury: A Systematic Review

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**ABSTRACT:** **Background**: Erb's palsy commonly refers to an upper-trunk brachial plexus birth injury affecting shoulder and elbow movement. Rehabilitation may include caregiver-guided range-of-motion activities, positioning, task-oriented training, splinting, constraint-induced movement therapy, neuromuscular electrical stimulation and therapy after nerve reconstruction. The evidence is diverse and often difficult to compare.

**Objective**: To synthesize available evidence on physiotherapy and closely related rehabilitation interventions for infants and children with Erb's palsy or brachial plexus birth injury, focusing on upper-limb motor function, range of motion, strength, activity, participation and longer-term outcomes.

**Methods**: This draft developed by cross-checking indexed reviews and primary-study information available through 13 October 2026, including PubMed records and open-access publisher pages. It uses a PRISMA-informed structure and proposes reproducible searches for MEDLINE/PubMed, Embase, Scopus, CENTRAL, CINAHL and PEDro. It is not presented as a completed de novo systematic review: database exports, duplicate removal, independent screening and full-text extraction have not been completed for this manuscript.

**Results**: A 2023 systematic review of randomized trials included seven studies after screening 932 titles and abstracts and reported low-certainty evidence across heterogeneous interventions and outcomes. A 2024 scoping review of rehabilitation following primary nerve surgery included 36 full-text articles and found that postoperative protocols and their stated aims varied. A 2024 systematic review and meta-analysis examined occupational-therapy interventions, while a 2025 review of long-term outcomes

synthesized 19 studies. A 2026 systematic review of neuromuscular electrical stimulation reported low-to-very-low certainty and substantial heterogeneity. These findings support the clinical relevance of rehabilitation but do not establish one universally superior protocol.

**Conclusion**: Rehabilitation for Erb's palsy should be individualized according to lesion severity, age, spontaneous recovery, surgery status and functional goals. The key research need is rigorous, transparent comparison of clearly described interventions using standardized measures and meaningful follow-up. No new pooled effect estimates or PRISMA study count is claimed in this draft.

## 1. INTRODUCTION

Brachial plexus birth injury (BPBI), also referred to as neonatal brachial plexus palsy or obstetric brachial plexus palsy, is a peripheral nerve injury sustained around the time of birth that can result in varying degrees of motor and sensory impairment in the affected upper limb. The clinical presentation ranges from transient weakness with spontaneous recovery to severe and persistent functional impairment, depending on the extent and anatomical distribution of the nerve injury (Khabyeh-Hasbani et al., 2024; Koshinski et al., 2022). Erb's palsy typically involves the upper trunk of the brachial plexus, predominantly affecting the C5–C6 nerve roots and may compromise shoulder abduction, external rotation and elbow flexion, thereby limiting the child's ability to perform age-appropriate upper-limb activities (Khabyeh-Hasbani et al., 2024; Swift, 2023).

Although spontaneous neurological recovery occurs in many affected infants, recovery is not always complete and some children experience persistent muscle weakness, restricted joint range of motion, muscle imbalance, contractures and secondary musculoskeletal deformities (Khabyeh-Hasbani et al., 2024; Koshinski et al., 2022). These impairments may extend beyond isolated deficits in muscle strength or joint mobility, affecting reaching, grasping, object manipulation and the coordinated use of both hands during everyday activities. Consequently, the clinical significance of BPBI extends beyond nerve recovery alone and includes the preservation of musculoskeletal integrity, the development of functional independence and participation in age-appropriate activities (Khabyeh-Hasbani et al., 2024; Blagovechtchenski et al., 2023).

Rehabilitation is an important component of the multidisciplinary management of children with BPBI, with treatment goals that may include maintaining joint mobility, preventing secondary contractures, facilitating motor recovery, improving upper-limb function and supporting the acquisition of developmentally appropriate skills (de Matos et al., 2023; Mehta&Sharma, 2024). Depending on the child's age, injury severity, pattern of spontaneous recovery and functional limitations, rehabilitation may incorporate passive and active range-of-motion exercises, appropriate positioning, caregiver education, task-oriented training, splinting and interventions designed to encourage active use of the affected limb (de Matoset al., 2023; Martínez-Carlón-Reina et al., 2024). Additional approaches, including constraint-induced movement therapy (CIMT), virtual reality-based training, augmented biofeedback, kinesiology taping and neuromuscular electrical stimulation, have also been investigated as adjuncts to conventional rehabilitation, although their indications and supporting evidence vary (Alsakhawi&Atya, 2020; De Miguel-Rubio et al., 2023; Hassan et al., 2020; Martínez-Carlón-Reina et al., 2024). Rehabilitation is central to managing pediatric neuromotor conditions, including brachial plexus birth injury and cerebral palsy. In children with cerebral palsy, adjunctive whole-body vibration may improve muscle architecture, joint range of motion, and functional performance (Ali et al., 2024). The rehabilitation needs of children who undergo surgical reconstruction may differ from those managed conservatively, as postoperative care must account for surgical healing, the procedure performed, the timing of rehabilitation and the progressive reintroduction of movement and functional training. However, published postoperative rehabilitation protocols vary in their therapeutic objectives and descriptions of treatment, limiting the ability to establish consistent recommendations across surgical approaches (Mendiratta et al., 2024). In their scoping review, Mendiratta et al. (2024) identified 36 full-text articles addressing rehabilitation after primary nerve surgery and reported variation in the aims and modalities of rehabilitation. These findings highlight the importance of considering rehabilitation in the context of the child's treatment pathway rather than assuming that a uniform intervention is appropriate for all children with BPBI.

Despite the growing range of available rehabilitation approaches, the evidence supporting their effectiveness remains difficult to interpret because of differences in study design, patient characteristics, intervention protocols, treatment intensity and outcome assessment. A systematic review of randomized controlled trials by de Matos et al. (2023) included seven studies from

932 screened titles and abstracts and reported substantial heterogeneity across interventions and outcomes, with low-certainty evidence for the effectiveness of physical therapy interventions. Similarly, the systematic review and meta-analysis by Martínez-Carlón-Reina et al. (2024) examined occupational therapy interventions in infants and children with obstetric brachial plexus palsy, including approaches such as CIMT, splinting, neuromuscular electrical stimulation and joint mobilization. Although these reviews provide valuable evidence concerning specific rehabilitation approaches, differences in their intervention scope and eligibility criteria make it important to interpret their findings in relation to the broader rehabilitation needs of children with BPBI.

Furthermore, the assessment of rehabilitation outcomes requires consideration of multiple domains, including active and passive range of motion, muscle strength, motor control, upper-limb activity, bimanual performance and functional participation. Improvements in impairment-level measures do not necessarily translate into equivalent improvements in everyday function, underscoring the importance of evaluating clinically meaningful outcomes alongside physical recovery (de Matos et al., 2023; Martínez-Carlón-Reina et al., 2024). The variability in outcome measures and follow-up periods across the literature also complicates comparisons between interventions and limits the extent to which findings can be translated into standardized clinical recommendations (de Matos et al., 2023; Mendiratta et al., 2024).

Accordingly, a systematic synthesis of the available evidence is warranted to evaluate physiotherapy and closely related rehabilitation interventions for infants and children with BPBI, with particular attention to Erb's palsy. This review aims to examine the effects of these interventions on upper-limb motor function, range of motion, muscle strength, activity performance, participation and longer-term functional outcomes. By considering differences in patient characteristics, intervention approaches, treatment context and outcome measurement, the review seeks to clarify the current evidence base, identify areas of uncertainty and inform future research and individualized rehabilitation planning for children with BPBI.

## 2. METHODS

### 2.1. Study Design and Reporting Framework

This study is designed to synthesize the available evidence on the effectiveness of physiotherapy and related rehabilitation interventions in infants and children with brachial plexus birth injury (BPBI), with particular attention to Erb's palsy. The review examine rehabilitation approaches used in both conservative management and postoperative care, while distinguishing between nonsurgical interventions and rehabilitation delivered following surgical reconstruction.

The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) reporting guideline. The review protocol, eligibility criteria, search strategy, study selection process, data extraction procedures and methods of evidence synthesis defined before the formal screening process begins. The completed manuscript report the procedures actually undertaken and not present proposed methods as completed research activities.

### 2.2. Research Question

**The primary research question is:**

What is the effectiveness of physiotherapy and related rehabilitation interventions in improving upper-limb motor function and functional outcomes in infants and children with brachial plexus birth injury?

The review also addresses the following secondary questions:

- Which rehabilitation interventions have been investigated in children with BPBI?
- What effects do these interventions have on active and passive range of motion, muscle strength, motor control and upper-limb activity?
- Do rehabilitation outcomes differ according to age, injury severity, intervention type, or surgical status?
- What evidence is available regarding participation in daily activities, bimanual function and longer-term outcomes?
- What methodological limitations and evidence gaps should be addressed in future research?

### 2.3. Eligibility Criteria

**Eligibility criteria**: structured according to the Population, Intervention, Comparison, Outcomes and Study design (PICOS) framework.

**Population**: Studies involving infants, children, or adolescents younger than 18 years diagnosed with BPBI, neonatal brachial plexus palsy, obstetric brachial plexus palsy, or Erb's palsy considered.

**Interventions:** Eligible interventions include physiotherapy, therapeutic exercises, passive and active range-of-motion activities, caregiver-guided rehabilitation, task-oriented training, constraint-induced movement therapy (CIMT), splinting and orthoses, virtual reality-based rehabilitation, mirror therapy, kinesiology taping, neuromuscular electrical stimulation and other clearly described rehabilitation approaches. Postoperative rehabilitation following nerve reconstruction or other surgical procedures considered separately.

**Comparators:** Eligible comparison conditions may include usual care, conventional physiotherapy, alternative rehabilitation interventions, no additional intervention, or pre-intervention measurements in studies using an appropriate single-group design. Comparative effectiveness assessed only where the study design permits meaningful comparison.

**Outcomes:** Primary outcomes include upper-limb motor function and active or passive range of motion. Secondary outcomes include muscle strength, motor control, functional use of the affected limb, bimanual performance, activities of daily living, participation, adverse events and longer-term functional outcomes.

**Study designs:** Randomized controlled trials and other eligible comparative clinical studies prioritized. Nonrandomized intervention studies may be included if they meet the prespecified eligibility criteria. Reviews may be used to identify relevant primary studies and contextualize the findings, but review-level and primary-study evidence distinguished to avoid double-counting participants or results.

### 2.4. Information Sources and Search Strategy

A comprehensive literature search planned for MEDLINE/PubMed, Embase, Scopus, the Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL and PEDro. Reference lists of relevant systematic reviews and included primary studies also be examined to identify additional eligible publications.

The search strategy combines controlled vocabulary, where available and free-text terms related to brachial plexus birth injury and rehabilitation. Search terms include variations of the following concepts:

- "Brachial plexus birth injury"
- "Obstetric brachial plexus palsy"
- "Neonatal brachial plexus palsy"
- "Erb's palsy"
- "physiotherapy"
- "Physical therapy"
- "Occupational therapy"
- "rehabilitation"
- "Constraint-induced movement therapy"
- "Neuromuscular electrical stimulation"
- "Virtual reality"
- "Functional outcomes"

**A draft PubMed search string is:**

("brachial plexus birth injury" OR "obstetric brachial plexus palsy" OR "neonatal brachial plexus palsy" OR "Erb's palsy") AND ("physical therapy" OR physiotherapy OR "occupational therapy" OR rehabilitation OR "constraint-induced movement therapy" OR "neuromuscular electrical stimulation" OR "virtual reality")

The final search strategies adapted to the indexing system and syntax of each database. The date of the final search, complete database-specific search strings, filters and numbers of retrieved records documented to support reproducibility.

### 2.5. Study Selection

All retrieved records compiled for duplicate identification and removal. Titles and abstracts then be screened against the predefined eligibility criteria, followed by full-text assessment of potentially relevant publications.

Where feasible, two reviewers independently conduct study selection and resolve disagreements through discussion or consultation with a third reviewer. Reasons for excluding studies at the full-text stage recorded. The selection process summarized in a PRISMA flow diagram, reporting the actual numbers of records identified, duplicates removed, records screened, full texts assessed and studies included.

### 2.6. Data Extraction

Data extracted using a standardized form developed for the review. The following information collected where available:

Author, publication year, country and study design.

- Participant characteristics, sample size, age and injury classification or severity.
- Surgical status and relevant details of previous procedures.
- Type of rehabilitation intervention and comparator.
- Treatment frequency, duration, intensity, setting and provider.
- Outcome measures and timing of assessments.
- Main findings, including between-group differences and within-group changes where appropriate.
- Adverse events, limitations and follow-up duration.

Data extraction distinguish findings from primary studies from conclusions reported in existing reviews. Missing or insufficiently reported information identified rather than inferred.

### 2.7. Risk of Bias and Certainty of Evidence

The methodological quality of included studies assessed using tools appropriate to their design. For randomized controlled trials, the Cochrane Risk of Bias 2 (RoB 2) tool may be used. For nonrandomized intervention studies, an appropriate tool, such as ROBINS-I, considered according to the study design and review scope.

The certainty of evidence for important outcomes assessed using the GRADE approach when sufficient information is available. Considerations include risk of bias, inconsistency, indirectness, imprecision and publication bias where assessable.

### 2.8. Data Synthesis

Study characteristics, rehabilitation approaches, outcome measures and findings initially be summarized descriptively. Studies grouped according to intervention type, clinical context and relevant outcome domain.

A quantitative meta-analysis considered only when studies are sufficiently comparable in terms of participants, interventions, comparators, outcomes and follow-up. Appropriate effect measures and confidence intervals reported where the available data permit their calculation. Statistical heterogeneity assessed using suitable methods when meta-analysis is justified.

If substantial clinical or methodological heterogeneity prevents meaningful pooling, a structured narrative synthesis undertaken. Findings from postoperative rehabilitation presented separately from those concerning nonsurgical rehabilitation when their clinical contexts differ substantially.

No pooled effect estimate generated without appropriate primary-study data. The final synthesis clearly distinguish statistically demonstrated effects, descriptive observations and conclusions limited by uncertainty in the available evidence.

## 3. RESULTS

### 3.1. Overview of the Available Evidence

The available literature indicates that rehabilitation for children with brachial plexus birth injury (BPBI) encompasses a range of interventions intended to improve upper-limb mobility, motor control, strength and functional use. These interventions include conventional physiotherapy, constraint-induced movement therapy (CIMT), mirror therapy, augmented biofeedback, virtual reality-based training, splinting and neuromuscular electrical stimulation (NMES).

The evidence base includes randomized controlled trials, nonrandomized clinical studies, systematic reviews and reviews of postoperative rehabilitation protocols. However, the available studies differ in participant age, injury characteristics, treatment duration, intervention intensity, outcome measures and follow-up periods. These differences limit direct comparisons across interventions.

De Matos et al. (2023) included seven randomized controlled trials following the screening of 932 titles and abstracts. The included studies involved infants and older children and investigated heterogeneous physical therapy interventions. The review reported low-certainty evidence, with the largest effects generally observed when an additional intervention combined with conventional physical therapy.

More recently, Koerner et al. (2026) synthesized 15 studies of nonsurgical rehabilitation interventions involving 558 participants aged 12 months to 18 years. The included literature covered several intervention categories, particularly CIMT and reflected variation in study quality and treatment protocols. This review provides an important recent source for identifying primary studies relevant to nonsurgical rehabilitation.

### 3.2. Characteristics of the Evidence

The characteristics of the principal published reviews identified for this synthesis are summarized in Table 1.

**Table 1.** Characteristics of relevant published reviews

| Review | Scope and evidence base | Main contribution |
|---|---|---|
| de Matos et al. (2023) | Seven randomized controlled trials identified from 932 screened titles and abstracts | Reported low-certainty evidence and substantial heterogeneity in physical therapy interventions and outcomes |
| Martínez-Carlón-Reina et al. (2024) | Systematic review and meta-analysis of occupational therapy interventions | Examined interventions intended to improve range of motion and upper-limb function in infants and children |
| Mendiratta et al. (2024) | Scoping review including 36 full-text articles concerning rehabilitation after primary nerve surgery | Identified variation in postoperative rehabilitation aims, modalities and timing |
| Pires et al. (2025) | Systematic review of long-term outcomes and interventions in neonatal brachial plexus palsy | Provides a source for evaluating longer-term functional outcomes and intervention-related evidence |
| Koerner et al. (2026) | Fifteen studies involving 558 participants, aged 12 months to 18 years, examining nonsurgical rehabilitation | Updated the evidence on conservative interventions, including CIMT and other rehabilitation approaches |

**Note**: This table summarizes published reviews rather than a newly completed systematic search. The full texts and reference lists should examined to establish the final set of eligible primary studies.

### 3.3. Findings by Rehabilitation Intervention

#### 3.3.1. Conventional Physiotherapy and Combined Interventions

Conventional physiotherapy forms a central component of rehabilitation for BPBI and commonly incorporates movement exercises and interventions intended to preserve joint mobility and facilitate functional use of the affected upper limb. The available evidence suggests that combining conventional physiotherapy with selected adjunct interventions may improve certain outcomes. Nevertheless, the magnitude and consistency of these effects remain uncertain because the studies differ in design, intervention protocols and outcome measures.

The systematic review by de Matos et al. (2023) found low-certainty evidence across seven randomized controlled trials. Its findings support continued investigation of combined treatment approaches but do not establish a single superior rehabilitation protocol.

### 3.3.2. Constraint-Induced Movement Therapy

CIMT is designed to encourage use of the affected upper limb by restricting the use of the less-affected limb for defined periods while providing structured practice with the affected arm. Studies included in the recent review by Koerner et al. (2026) investigated CIMT in children with BPBI, including treatment combined with conventional therapy.

The available evidence supports considering CIMT as a potentially useful intervention for selected children who can participate safely and actively in structured practice. However, differences in treatment dose, participant selection and outcome measurement prevent a definitive conclusion about its comparative effectiveness across all children with BPBI.

### 3.3.3. Mirror Therapy

Sari et al. (2023) conducted a randomized controlled study involving 20 children allocated to a conventional rehabilitation group or a group receiving additional mirror therapy. Both groups received routine physiotherapy for eight weeks.

The study found improvements in several measures of hand function within the treatment groups. However, mirror therapy did not demonstrate consistent additional benefits over routine physiotherapy across the assessed outcomes. Wrist extension improved in the mirror therapy group, while improvements in the Nine-Hole Peg Test and Box and Block Test observed in both groups. The authors noted that the study not sufficiently powered to establish whether mirror therapy provided additional benefits. These findings suggest that mirror therapy may be a useful adjunct for selected functional goals, but its incremental effectiveness remains uncertain.

### 3.3.4. Augmented Biofeedback and Technology-Assisted Rehabilitation

Augmented biofeedback and virtual reality-based interventions investigated as methods of increasing engagement, providing visual feedback and encouraging repeated upper-limb movement. Their proposed value lies in supplementing conventional therapy with structured, goal-directed practice. The evidence remains heterogeneous and the availability of positive findings in individual studies does not establish superiority over conventional rehabilitation. Interpretation requires consideration of the intervention dose, the specific outcome measured, the quality of the study design and the extent to which observed changes translate into everyday activities.

### 3.3.5. Neuromuscular Electrical Stimulation

NMES investigated as an adjunct intended to facilitate muscle activation and support motor recovery. The clinical rationale for its use is relevant to children with weakness or impaired voluntary activation, although the effects may depend on the underlying nerve injury, muscle status, treatment parameters and rehabilitation context. Evidence concerning NMES should interpreted cautiously because stimulation protocols and clinical outcomes vary across studies. The available evidence does not justify recommending a single standardized stimulation protocol for all children with BPBI.

### 3.3.6. Postoperative Rehabilitation

Postoperative rehabilitation represents a distinct clinical context because treatment must account for surgical healing, the reconstruction procedure, the timing of permitted movement and the goals of nerve recovery. Mendiratta et al. (2024) identified 36 full-text articles describing rehabilitation following primary nerve surgery for upper-trunk BPBI. The reported average initiation of rehabilitation 22.26 days after surgery. Among the articles classified by rehabilitation aim, nine described passive movement, nine described active or task-oriented movement and five described interventions intended to facilitate initial motor recovery. The review also found differences in the reporting of active therapy according to surgical approach.

These findings demonstrate substantial variation in postoperative rehabilitation protocols and highlight the need for clearer descriptions of treatment timing, restrictions, exercise progression and functional goals.

### 3.4. Summary of Outcome Domains

The outcome domains addressed across the literature are summarized in Table 2.

**Table 2.** Rehabilitation outcomes and interpretation

| Outcome domain | Examples of assessment | Interpretation for BPBI rehabilitation |
|---|---|---|
| Active range of motion | Active shoulder, elbow, wrist and finger movement | Indicates the ability to move the affected limb voluntarily |
| Passive range of motion | Goniometric joint measurements | Helps assess joint mobility and potential contractures |
| Motor function | Active Movement Scale and Modified Mallet Scale | Assesses movement quality and selected upper-limb functions |
| Strength and grasp | Hand grip and finger grip strength tests | Evaluates force production and distal upper-limb performance |
| Unilateral and bimanual activity | Box and Block Test, Nine-Hole Peg Test and functional activity measures | Assesses object manipulation, dexterity and task performance |
| Participation and daily function | Age-appropriate activity and participation measures | Evaluates the relevance of impairment-level improvements to everyday life |
| Longer-term outcomes | Follow-up measurements of function and musculoskeletal status | Helps identify persistence of gains and later functional limitations |

The outcomes reported in individual studies should not be assumed to interchangeable. In particular, improvements in isolated joint movement or grip strength do not necessarily indicate equivalent improvements in bimanual performance or participation in daily activities.

### 3.5. Overall Synthesis

The available evidence indicates that rehabilitation is an important component of BPBI management, but the certainty of evidence differs across intervention types and outcome domains. Some studies report improvements in specific measures following adjunct interventions, whereas others show no clear additional benefit compared with conventional physiotherapy.

The principal limitations of the current evidence include small samples in individual trials, variation in treatment protocols, inconsistent outcome measurement and limited comparability across populations and follow-up periods. A definitive ranking of rehabilitation interventions cannot established from the published information summarized here.

## 4. DISCUSSION

This synthesis indicates that rehabilitation for children with brachial plexus birth injury should be understood as a multidimensional process rather than a single standardized intervention. The available literature addresses preservation of joint mobility, improvement of motor control, development of upper-limb strength and promotion of functional use in everyday activities. However, the certainty of evidence and the consistency of reported effects vary between interventions. The systematic review by de Matos et al. (2023) identified low-certainty evidence across seven randomized controlled trials, emphasizing the methodological and clinical heterogeneity of physical therapy research in BPBI. In contrast, the 2026 review by Koerner et al. reported supportive evidence for several nonsurgical interventions, including CIMT, NMES and virtual reality. These findings should not be interpreted as contradictory without considering differences in eligibility criteria, intervention scope, included studies and methods of evaluating evidence quality. Importantly, the review by Koerner et al. focused on selected nonsurgical interventions and excluded studies with sample sizes of 20 or fewer participants. Its findings therefore cannot automatically be generalized to every rehabilitation approach, infant population, or postoperative context. Conventional physiotherapy remains a central component of BPBI management because treatment may need to address joint mobility, muscle imbalance, motor recovery and the development of age-appropriate movement. Its role may differ according to injury severity, the child's stage of recovery and the presence of secondary musculoskeletal complications. The available evidence does not establish that one conventional physiotherapy protocol is superior to all others. Differences in exercise selection, frequency, intensity, caregiver

involvement and duration make comparisons difficult. Future trials should provide detailed descriptions of treatment content and dosage so that effective components can identified and reproduced in clinical practice. CIMT, mirror therapy, biofeedback and technology-assisted interventions seek to increase active engagement and promote use of the affected limb. Their potential value is clinically relevant, particularly when conventional treatment alone does not sufficiently encourage functional movement practice.

Nevertheless, evidence of improvement within an intervention group is not equivalent to evidence of superiority over a comparator. The randomized study by Sari et al. (2023), for example, found improvements in selected measures after mirror therapy added to routine rehabilitation, but did not establish consistent additional benefits across the measured outcomes. The limited sample size also reduces confidence in conclusions about comparative effectiveness.

Similarly, findings supporting CIMT or virtual reality should be interpreted in relation to participant selection, treatment dose and the specific outcomes assessed. These approaches may be appropriate adjuncts for selected children, but the current evidence does not justify treating them as universally superior alternatives to conventional rehabilitation.

NMES is a particularly relevant area for further research because it is intended to facilitate muscle activation and may be combined with active exercise or task-oriented rehabilitation. The 2026 systematic review by Celbek et al. included seven randomized controlled trials involving 197 participants. Although several studies reported improvements in selected motor and strength outcomes, the authors identified substantial heterogeneity and rated the certainty of evidence as low to very low.

These findings support cautious consideration of NMES as an adjunct rather than a stand-alone solution. Clinical decisions should account for the child's neurological status, muscle response, treatment tolerance and rehabilitation goals. Standardized reporting of stimulation parameters and longer follow-up are needed before more definitive recommendations can be made.

Rehabilitation following nerve reconstruction requires separate consideration because the timing and progression of treatment are influenced by surgical healing, the reconstruction technique and the clinical team's assessment of recovery.

Mendiratta et al. (2024) demonstrated that postoperative rehabilitation protocols vary considerably in their stated aims and therapeutic modalities. This variation limits the development of uniform recommendations and highlights the need for more explicit descriptions of postoperative restrictions, initiation of movement, exercise progression and criteria for advancing therapy.

Postoperative findings should not be directly combined with nonsurgical rehabilitation results without accounting for differences in patient characteristics and clinical objectives. Children undergoing surgery may have more severe injuries or different recovery trajectories than children managed conservatively.

An important consideration is the distinction between impairment-level outcomes and functional performance. Increased range of motion or muscle strength may be clinically beneficial, but these changes do not necessarily translate into improved independence, bimanual coordination, or participation in daily activities.

The use of standardized measures of motor function, dexterity and activity performance can help establish whether physiological improvements are meaningful to children and their families. Future research should also incorporate age-appropriate measures of participation and caregiver-reported outcomes, alongside objective physical assessments.

Long-term follow-up is particularly important because children may develop secondary limitations as their activity demands increase. Evaluating outcomes beyond the immediate treatment period would help determine whether rehabilitation gains persist and whether additional treatment is required.

A strength of the existing literature is the increasing attention to a range of rehabilitation modalities and functional outcomes. The availability of randomized trials and recent systematic reviews provides a foundation for evaluating both established and emerging interventions.

However, important limitations remain. Individual studies often include relatively small samples and the clinical characteristics of participants vary. Differences in injury severity, age, surgical history, intervention dosage and outcome measurement limit comparability. In addition, some outcomes are measured only immediately after treatment, restricting conclusions about durability.

A further limitation for the present manuscript is that its current synthesis is based on published reviews and accessible primary-study information rather than a completed independent systematic review. The database search, duplicate removal, independent screening, full-text eligibility assessment and standardized extraction of all potentially eligible primary studies have not yet been completed. Consequently, the findings should be interpreted as a preliminary evidence synthesis and not as the final results of a newly completed PRISMA systematic review.

Future research should prioritize adequately powered randomized controlled trials with clearly defined intervention protocols and appropriate comparison groups. Studies should report intervention frequency, intensity, duration, adherence and concurrent treatments in sufficient detail to support replication.

A core set of outcome measures would improve comparability across studies. Such a set should include active and passive range of motion, motor function, strength, unilateral and bimanual activity, participation, adverse events and longer-term outcomes.

Researchers should also report results according to relevant clinical characteristics, including age, injury severity and surgical status. Finally, direct comparisons between adjunct interventions and well-described conventional physiotherapy protocols would help establish which approaches provide meaningful additional benefits.

## 5. CONCLUSION

Rehabilitation plays an important role in the management of children with brachial plexus birth injury by addressing limitations in joint mobility, muscle strength, motor control and upper-limb function. The available literature describes a broad range of interventions, including conventional physiotherapy, constraint-induced movement therapy, mirror therapy, biofeedback, virtual reality-based training, neuromuscular electrical stimulation and postoperative rehabilitation.

Current evidence suggests that selected adjunct interventions may provide benefits for specific motor or functional outcomes. However, differences in study design, participant characteristics, intervention protocols, outcome measures and follow-up periods limit direct comparisons and prevent the identification of a single universally superior rehabilitation approach. Evidence supporting several interventions remains uncertain and improvements in physical impairment measures should not automatically interpreted as improvements in everyday function or participation. Rehabilitation should therefore be individualized according to the child's age, injury severity, pattern of recovery, surgical history and functional goals. Future research should use rigorous comparative designs, standardized outcome measures, clearly reported intervention protocols and longer follow-up periods to establish the effectiveness and clinical relevance of different rehabilitation approaches. Hence, the current evidence supports individualized, goal-directed rehabilitation for children with brachial plexus birth injury (BPBI), although stronger evidence needed to identify the most effective interventions and improve long-term functional outcomes. This review limited by the incomplete database search, study selection, data extraction and risk-of-bias assessment, as well as heterogeneity in participants, interventions, outcome measures and follow-up periods. Therefore, the findings should interpreted cautiously until a comprehensive and reproducible systematic review is completed.

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