Exploring the Role of Neuromuscular Electrical Stimulation in Neonatal Brachial Plexus Palsy: A Narrative Review of Motor Recovery and Functional Outcomes

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Abstract

Objective: This narrative review examines the role of neuromuscular electrical stimulation (NMES), particularly reciprocal electrical stimulation (RES), in enhancing motor function and limb recovery in infants with neonatal brachial plexus palsy (NBPP).
Methods: A literature search was conducted from 2021 to 2024 using PubMed, Google Scholar, and PEDro, focusing on randomized controlled trials (RCTs) and pilot RCTs. A narrative synthesis was employed due to the limited number of eligible studies.
Results: Three studies met the inclusion criteria. NMES has demonstrated promising outcomes in promoting motor recovery and reducing muscle degeneration, with RES showing particularly beneficial effects.
Conclusion: NMES, specifically RES, may be therapeutically valuable in NBPP rehabilitation. However, further high-quality and standardized studies are needed to confirm these findings.

Keywords: Neonatal brachial plexus palsy, neuromuscular electrical stimulation, reciprocal electrical stimulation.

Introduction

Weakness or flaccid paralysis of the upper limb identified shortly after birth, known as neonatal brachial plexus palsy (NBPP), is caused by damage to one or more nerve roots from C5 to T1. The worldwide occurrence of NBPP varies between 0.38 and 5.1 per 1,000 live births, with differences observed across regions based on factors such as study location (e.g., individual hospitals, specific populations), population-based data, and access to maternal-fetal healthcare. NBPP often results in long-lasting consequences and can be a debilitating condition. Beyond physical and functional limitations, NBPP can affect family relationships, overall child development, and quality of life [1].

The brachial plexus consists of a network of peripheral nerves originating from the anterior (ventral) rami of the spinal nerves C5-T1. These nerves function as electrical conduits, transmitting commands from the brain to the arm muscles and conveying sensory information to and from the muscles of the shoulder, elbow, wrist, and hand [2]. Nerve compression or strain is the primary cause of brachial plexus injury, although various other factors may contribute. Newborns are particularly vulnerable to these injuries during childbirth, with specific weakness patterns emerging based on the affected areas of the brachial plexus. The most severe form of injury is nerve root avulsion, which leads to complete paralysis of the associated muscle. Brachial plexus traction injuries occur when the plexus is excessively stretched during delivery, typically related to challenging breech extractions, even in small infants, or cephalic presentations in large infants with shoulder dystocia [3].

The stretching of brachial plexus nerves (C5 to T1) in the perinatal period results in arm weakness or paralysis, causing limitations in the active range of motion (AROM) [4]. Although not universally present, the application of traction to the neck during difficult deliveries is frequently observed in neurological birth injuries, including the aforementioned condition. Contrary to the common belief that obstetricians' delivery techniques are solely responsible, mismanagement during shoulder dystocia can still cause NBPP [5]. Neonatal brachial plexus palsy (NBPP) classification is based on the nature and patterns of nerve damage. The Narakas classification system divides NBPP into four categories.

1. Group I: Classic Erb's Palsy, involving injury to the C5 or C6 nerve roots. This results in diminished strength or paralysis, affecting shoulder abduction, external rotation, elbow flexion, and forearm supination.
2. Group II: Extended Erb's Palsy builds upon Group I by including damage to the C5-C7 nerve roots. In addition to the symptoms observed in Classic Erb's palsy, patients also experience a lack of wrist and digital extension.
3. Group III: Total Palsy without Horner's syndrome, affecting all plexus roots (C5-T1), leading to complete flaccid paralysis of the affected limb. However, Horner's syndrome, characterized by miosis, ptosis, and ipsilateral facial anhidrosis, was not observed.
4. Group IV: Total Palsy with Horner's syndrome, the most severe form. This category involved all plexus roots (C5-T1) as well as the sympathetic chain. It manifests as complete flaccid paralysis of the affected limb, accompanied by Horner's syndrome, indicating sympathetic chain involvement and an avulsion injury. Additionally, phrenic nerve palsy and elevated ipsilateral hemidiaphragm may be observed.

The extent and severity of nerve damage influence recovery. Approximately 20%–30% of infants experience ongoing impairment in upper limb function and fine motor skills, leading to difficulties in reaching developmental milestones or facing challenges in self-care and instrumental activities of daily living throughout their lives. Some babies undergo initial nerve surgery to promote nerve regeneration and muscle reinnervation. The timing of surgical intervention varies, but the absence of biceps and shoulder recovery typically indicates the need for primary nerve repair. Consequently, restoration of biceps function is generally considered the primary focus of NBPP treatment [4].

Rehabilitation, including occupational and physical therapy, plays a crucial role in the conservative, preoperative, and postoperative management of NBPP [4]. The primary goals of therapy include preventing contractures and joint deformities, strengthening muscles while maintaining a balance between agonists and antagonists, promoting active movement, and improving participation in daily activities in alignment with the International Classification of Functioning (ICF) [6].

One approach frequently used by therapists is neuromuscular electrical stimulation (NMES). This technique employs a handheld, battery-powered device programmed to deliver electrical currents through surface electrodes placed on the target muscles. The objective is to facilitate improvements in the active range of motion (AROM) and/or muscle strength [4]. NMES functions by applying controlled electrical impulses to the affected muscle groups, with parameters such as frequency, pulse duration, amplitude, and electrode placement carefully selected to optimize therapeutic outcomes. The specific settings, duration of treatment, equipment used, electrode positioning, and accompanying therapies can vary significantly [3].

Reciprocal electrical stimulation (RES) is a neuromuscular electrical stimulation technique that sequentially activates motor units in both agonist and antagonist muscles. This stimulation pattern was designed to replicate the natural firing sequence of healthy muscles. Furthermore, we hypothesized that RES may enhance the strength of the antispastic muscle while simultaneously reducing cortical excitability in the spastic muscle. Additionally, by stimulating sensory receptors and neurons within both muscle groups, RES has the potential to increase the neural drive and promote improved motor function [2].

This review aimed to evaluate the effectiveness of NMES, particularly RES, in the management of NBPP. By analyzing the existing literature on NMES application, treatment protocols, and patient outcomes, this review aims to determine its role in improving motor function, muscle strength, and overall limb function in infants with NBPP.

Methods

Data Sources and Searches

An extensive literature analysis was performed to assess the effectiveness of Neuromuscular Electrical Stimulation in treating Neonatal Brachial Plexus Palsy. Two independent reviewers conducted the search between November 2024 and January 2025. The systematic search encompassed three electronic databases: PubMed, Google Scholar, and Physiotherapy Evidence Database (PEDro). The study design was limited to RCTs, and only English-language publications from 2021 to 2024 were included. To ensure a comprehensive search, Boolean operators were employed, combining terms such as Neuromuscular Electrical Stimulation OR NMES with Neonatal Brachial Plexus Palsy OR NBPP OR Erb's palsy OR infant OR newborn. The inclusion criteria primarily focused on RCTs and pilot RCTs that investigated the impact of Neuromuscular Electrical Stimulation on Neonatal Brachial Plexus Palsy treatment. The review process adhered to the PRISMA 2020 guidelines for transparency and reproducibility.

The PICO methodology was structured as follows:

- Population: Infants with confirmed Neonatal Brachial Plexus Palsy (NBPP)
- Intervention: Neuromuscular Electrical Stimulation (NMES), including RES
- Comparison: Standard physical or occupational therapy
- Outcome: Improvements in motor function, muscle strength, and limb functionality

Study Selection

The review selection process encompassed a thorough examination of titles and abstracts, followed by an evaluation of full-text articles to assess eligibility. The inclusion of studies in this comprehensive review was contingent upon meeting the following specific criteria:

Inclusion Criteria:

- Research studies eligible for inclusion encompassed randomized controlled trials (RCTs) or pilot RCTs that investigated the effects of Neuromuscular Electrical Stimulation on Neonatal Brachial Plexus Palsy.
- Eligible studies must have involved participants who were diagnosed with Neonatal Brachial Plexus Palsy.
- Studies have reported outcomes such as improved motor function, muscle strength, and overall limb function in infants with NBPP.
- Studies published in English and available as full-text PDFs were included.

Exclusion Criteria:

Studies were excluded based on the following criteria:

- Non-randomized trials, observational studies, and case reports.
- Studies focused on conditions other than Neonatal Brachial Plexus Palsy.
- Research that did not specifically examine the effects of neuromuscular electrical stimulation on improving motor function, muscle strength, and overall limb function in neonates with brachial plexus palsy.

- Articles that had not undergone peer review or lacked sufficient data for outcome analysis.
- Studies not published in English or not accessible as full-text PDF documents.

Discrepancies in the study selection were resolved through discussion and consensus.

Data Extraction

Data were extracted by two independent reviewers. The collected information encompassed study characteristics (author, publication year, and study design), participant information (sample size, demographics, and clinical features), and intervention details (specifics of Neuromuscular Electrical Stimulation, including treatment frequency and duration). The outcome measures included improvements in motor function, muscle strength, and overall limb function. The analysis focused on the efficacy of each intervention, emphasizing the statistical significance and comparative effectiveness of the key findings.

Quality Assessment

The methodological quality and risk of bias of the included studies were assessed using two well-established tools: the Cochrane Risk of Bias tool (ROB2) and the Physiotherapy Evidence Database (PEDro) Scale. These tools were applied independently to capture both internal validity and potential sources of bias.

Risk of Bias Assessment (ROB2)

The Cochrane Risk of Bias (ROB2) tool was used to evaluate five key domains: randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results. Each domain was rated as low risk (✓), high risk (X), or some concerns (?), and an overall judgment was made for each study accordingly.

Table 1. Summary of ROB2 Assessment

Study Included	Bias from the Randomization Process	Bias Due to Deviations from Intended Intervention	Bias Due to Missing Outcome Data	Bias in Measurement of Outcome	Bias in Selection of Reported Results
Elnegamy, T. E. (2024)	**?**	✓	✓	**X**	**X**
Justice, D. et al. (2023)	✓	✓	✓	✓	✓
Abdelaziz, E. R. (2022)	**?**	**?**	✓	**X**	**X**

Legend:
✓ = Low risk X = High risk ? = Some concerns

- Elnegamy et al. (2024) provided information on dropout rates and blinding, suggesting a low risk of bias in some areas. However, the absence of details regarding trial registration and concerns in outcome reporting resulted in an overall high risk of bias.

- Justice et al. (2023) demonstrated methodological rigor across all five ROB2 domains, resulting in an overall low risk of bias.

- Abdelaziz et al. (2022) showed insufficient details regarding the randomization process and intervention integrity. Combined with missing information on blinding and registry status, the overall judgment for this study was also high risk of bias.

PEDro Scale Assessment

To further evaluate methodological rigor, the PEDro Scale was applied. The PEDro scale is a validated instrument widely used in physical therapy research to assess randomized controlled trials (RCTs) based on 11 criteria—1 addressing external validity (not scored) and 10 related to internal validity, including random allocation, allocation concealment, blinding, and statistical reporting [7,8]. Consistent with common practice in systematic reviews, the external validity criterion was not included in the scoring [9].

Based on PEDro scores, studies were classified as follows:

- 7–10 = High quality
- 5–6 = Fair quality
- ≤4 = Poor quality [10]

Of the three studies included in this review:

- One had an existing peer-reviewed PEDro score, which was verified by two independent reviewers.
- The remaining two studies were newly assessed by the same independent reviewers using the PEDro scale.

The consistency and reliability of the PEDro scale for rating clinical trials has been rated as excellent to fair, supporting its use in this review [11].

Table 2. PEDro Scores of Included Studies

Study Reference	2	3	4	5	6	7	8	9	10	11	Total Score	Study Quality
Tamer Emam Elnegamy (2024)	Y	N	Y	N	N	Y	Y	Y	Y	Y	7	High
Denise Justice (2023)	Y	N	Y	Y	Y	Y	Y	N	Y	Y	8	High
Emad R. Abdelaziz (2022)	Y	N	Y	N	N	N	Y	N	Y	Y	5	Fair

Scoring Criteria Key:

- Y = Criterion satisfied
- N = Criterion not satisfied

PEDro Criteria:

1. Eligibility criteria were specified (not scored)
2. Subjects were randomly allocated to groups
3. Allocation was concealed
4. The groups were similar at baseline regarding key prognostic indicators
5. There was blinding of all subjects

6. There was blinding of all therapists administering the therapy
7. There was blinding of all assessors measuring at least one key outcome
8. Outcome measures were obtained from more than 85% of subjects initially allocated
9. All subjects received treatment as allocated or were analyzed using intention-to-treat
10. Between-group statistical comparisons were reported for at least one key outcome
11. The study provided both point measures and variability measures for at least one key outcome

Interpretation of PEDro Scores

The PEDro scores for the included studies ranged from 5 to 8, with a mean score of 6.67 (SD = 1.25), reflecting an overall fair quality across the evidence base.

- Elnegamy et al. (2024) scored 7/10, indicating high quality. The study fulfilled the criteria related to randomization, outcome reporting, and assessor blinding, but did not satisfy therapist or subject blinding or allocation concealment.
- Justice et al. (2023) achieved the highest score (8/10), meeting most of the internal validity benchmarks. The only unmet criteria were allocation concealment and subject blinding.
- Abdelaziz et al. (2022) scored 5/10, indicating fair quality. It met fewer methodological criteria, lacking subject and therapist blinding, as well as allocation concealment.

These findings suggest variability in methodological rigor among the studies, with two meeting high-quality thresholds and one falling short. Importantly, none of the studies satisfied criterion 3 (allocation concealment), which is a critical factor for minimizing selection bias.

Data Synthesis

Due to the variability in study designs, outcome measures, and intervention protocols, a narrative synthesis approach was employed to compare the results of the included studies. This synthesis concentrated on the effects of Neuromuscular Electrical Stimulation in enhancing motor function, muscle strength, and overall limb function. The synthesis was organized based on the quality of the studies, with higher-quality studies given more weight in the analysis. When possible, the results were compiled into tables for better clarity. Because of the heterogeneity in study designs, outcome measures, and treatment protocols, a meta-analysis was not feasible, leading to the adoption of a descriptive approach.

The PRISMA flow diagram (Figure 1), which describes the study's identification procedure, abstract screening results, and full-text eligibility assessments, including the rationale for exclusions, was followed for data synthesis. Finally, three articles fulfilled the eligibility criteria for full-text evaluation.

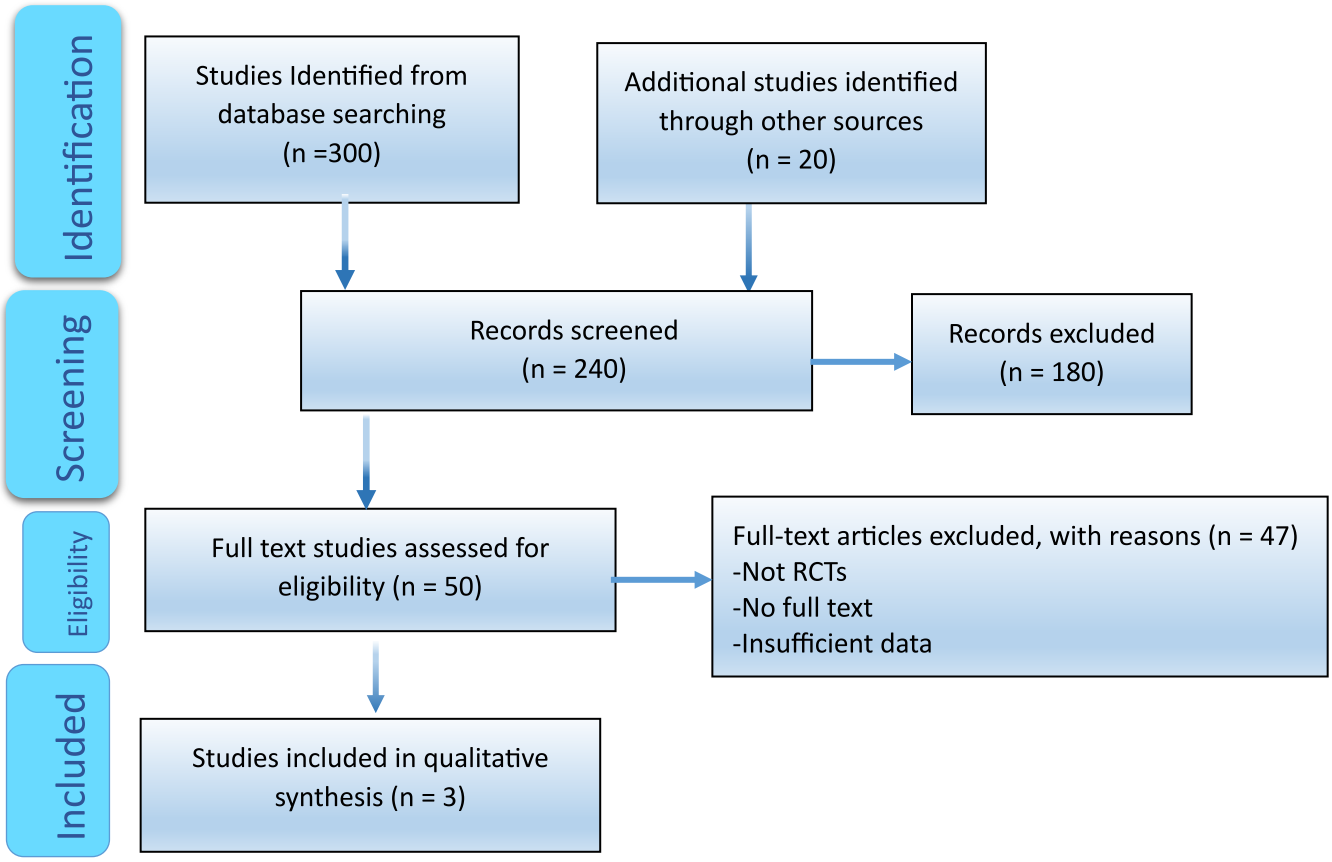

Figure 1. PRISMA 2020 Flow Diagram for Study Selection in this systematic review.

Results

The initial screening identified 50 potential studies for inclusion. Upon examining the abstracts, only 3 met the specified criteria (Fig. 1). Two of these were randomized controlled trials [2,3], while the third was a randomized controlled trial (RCT) pilot study [4]. All three studies involved children of both sexes diagnosed with Neonatal Brachial Plexus Palsy. The participants exhibited varying symptom durations and ages, ranging from 2 months to 3 years. The studies employed six distinct outcome measures, with electromyography being the most frequently used [2,3]. These measures have been validated as reliable indicators of clinical improvements. The post-intervention follow-up period ranged from immediate to 3 months. (Table 2)

Methodological quality assessment

(Table 1) displays the PEDro scores of each study. The scores ranged from five to eight, with an average of 6.67 (SD 1.25), indicating an overall 'fair' quality of research. Two studies were classified as 'high' quality, while one was deemed 'fair' [2,4]. All included studies met five PEDro criteria: random allocation, baseline comparability, outcome for >85%, between-group statistical comparisons, and reporting of point measures and variability [2,3,4]. None of the studies fulfilled criterion three, and only one satisfied criterion five regarding subject blinding [4].

Analysis

Table 3: NMES Protocol Summary

Study	NMES Type	Frequency	Duration	Electrode Placement	Parameters Reported?
Elnegamy et al. (2024)	RES	3x/week	15 mins	Elbow muscles	Not fully reported
Justice et al. (2023)	NMES	Daily	30 mins	Not specified	Partial
Abdelaziz et al. (2022)	RES	3x/week	Not specified	Not specified	Not specified

Table 4: Study characteristics

Article	Control Group	Experimental Group	Sample Size	Frequency	Assessment post-intervention	Follow-Up	Key Results
Elnegamy et al. (2024)	Standard Physical Therapy	Standard Physical Therapy + 15-minute RES (3x/week)	40	3 times per week for 3 months	Percentage of degeneration (RD) with electromyography & TAMS (Toronto Active Motion Scale)	Immediate	Significantly greater reduction in RD and increased TAMS scores in the study group.
Justice et al. (2023)	Standard Therapy	Standard Therapy + NMES (30 min daily)	17	30 min daily for 3 months	AROM, muscle strength, morphometric measurements	1, 2, & 3 months	Significant improvement in elbow flexion AROM in the NMES group after the first month. No adverse effects.
Abdelaziz et al. (2022)	A specially designed physical therapy	Same physical therapy program + reciprocal electrical stimulation	30	3 sessions/week for 3 months	Percentage of degeneration (RD) with (Electroneurography)	Not specified	Improvement in functional recovery of the upper limb in both groups, but significantly greater in the

	program only						group receiving reciprocal electrical stimulation.

The included studies examined the efficacy of Neuromuscular Electrical Stimulation (NMES) as an adjunctive treatment for infants with neonatal brachial plexus palsy (NBPP) in addition to regular physical therapy. The studies varied in terms of their stimulation protocols, outcome measures, and follow-up periods. According to all studies, even with some methodological differences, infants receiving NMES showed meaningful improvements in functional recovery and muscle activation compared to the control groups.

Table 5. Summary of Reported Effects of NMES and RES in Included Studies

Study	**Intervention**	**Control**	**Outcome Measures**	**Effect**	**Reported Significance**	**Effect Direction**	**Study Quality (PEDro)**
Elnegamy et al. (2024)	RES + Standard PT (3x/week, 15 min)	Standard PT	RD (degeneration% % via EMG), TAMS	Significant improvement in TAMS, reduction in RD	Yes (statistically significant)	Large improvement in motor recovery	High (7/10)
Justice et al. (2023)	NMES + Standard Therapy (30 min daily)	Standard Therapy	AROM (elbow flexion), muscle strength, morphometrics	Significant improvement in elbow AROM at 1, 2, and 3 months	Yes	Moderate improvement in specific motor function	High (8/10)
Abdelaziz et al. (2022)	RES + Custom PT Program (3x/week)	Custom PT Program	RD (via ENG), functional recovery	Greater functional recovery in the RES group	Yes	Large improvement in function and neural input	Fair (5/10)

This table summarizes the clinical effects of Neuromuscular Electrical Stimulation (NMES) and Reciprocal Electrical Stimulation (RES) in infants diagnosed with Neonatal Brachial Plexus Palsy (NBPP), as reported in the three included studies. It highlights the type of intervention, sample size, key outcome measures, and direction and magnitude of the observed effects. Despite methodological and protocol differences, all studies reported favorable outcomes with NMES or RES in improving motor recovery, reducing muscle degeneration, and enhancing functional limb use. These findings suggest that NMES, especially RES, may offer clinical benefits as a complementary rehabilitation strategy for NBPP.

1. Impact on Muscle Degeneration and Functional Recovery

Two studies [Elnegamy et al. (2024) and Abdelaziz et al. (2022)] employed electromyography (EMG) and electroneurography (ENG) to thoroughly investigate muscle degeneration. According to both studies, electrical stimulation resulted in significantly less muscle degeneration (RD) in the experimental groups compared to the control groups receiving standard therapy. The Elnegamy et al. (2024) study demonstrated a clear improvement immediately following the intervention; conversely, the Abdelaziz et al. (2022) study did not specify their follow-up duration. Furthermore, Abdelaziz et al. (2022) reported significantly greater upper limb functional recovery in a large number of infants who experienced markedly improved outcomes with reciprocal electrical stimulation, highlighting its substantial advantage over standard physical therapy alone.

2. Improvement in Active Range of Motion (AROM) and Muscle Strength

Justice et al. (2023) specifically measured several key AROM parameters, a comprehensive range of muscle strength metrics, and various morphometric parameters in a cohort of infants who received NMES for 30 minutes each day over a three-month period. One month after the intervention, there was a significant improvement in elbow flexion AROM. This improvement continued at one, two, and three months of follow-up. The lack of reported adverse effects indicates that newborn NMES use is safe and tolerable.

3. Differences in NMES Protocols and Their Effectiveness

The studies employed different stimulation parameters.

- Elnegamy et al. (2024) used 15-minute repetitive electrical stimulation (RES) three times per week, demonstrating a significant increase in TAMS (Toronto Active Motion Scale) scores and reduced muscle degeneration.
- Justice et al. (2023) implemented a higher frequency protocol (30 min daily), resulting in notable improvements in elbow flexion within a month.
- Abdelaziz et al. (2022) applied reciprocal electrical stimulation three times per week, yielding the greatest functional recovery among the three studies.

Despite these variations, all three studies concluded that electrical stimulation enhances motor recovery and reduces muscle degeneration when used in conjunction with conventional physical therapy.

Discussion

This review suggests that NMES, particularly RES, may provide potential therapeutic benefits for infants with NBPP when used alongside conventional physical therapy. While all three studies reported positive trends in motor recovery and muscle preservation, the limited sample sizes and methodological variability limit the ability to draw definitive conclusions from these studies. The studies examined consistently showed that NMES, when used alongside traditional physical therapy, improved motor recovery, reduced muscle deterioration, and enhanced muscle strength in patients with hemiplegia. NMES achieves these benefits by activating both motor and sensory pathways, promoting neuroplasticity, and improving motor control and functional recovery. RES, in particular, seems to mimic natural muscle activation patterns, potentially leading to more coordinated movements and better motor learning in affected infants than TMS.

A key discovery in this review is the significant reduction in muscle degeneration observed in the studies by Elnegamy et al. (2024) and Abdelaziz et al. (2022) Using electromyography (EMG) and electroneurography (ENG), these studies provided objective evidence that infants receiving NMES experienced less muscle degeneration than those undergoing standard therapy alone. The preservation of muscle integrity is crucial for better long-term functional outcomes. Additionally, Abdelaziz et al. (2022) reported that infants treated with RES showed superior upper limb functional recovery, suggesting that this specific NMES technique may be more effective than traditional physical therapy in enhancing neuromuscular re-education and muscle recruitment.

Justice et al. (2023) focused on improvements in active range of motion (AROM) and muscle strength, revealing significant gains in elbow flexion AROM that persisted over a three-month follow-up period. This finding underscores the potential of NMES to produce both immediate and lasting functional improvements. The absence of reported adverse effects across all studies emphasizes the safety and tolerability of NMES in neonatal populations, which is particularly important, given the vulnerability of this age group. This favorable safety profile supports the inclusion of NMES in early intervention programs for NBPP, potentially accelerating developmental milestones and enhancing the quality of life.

Despite these promising outcomes, the variation in NMES protocols across studies, including differences in stimulation frequency, session duration, and electrode placement, makes it challenging to determine the most effective therapeutic regimens. For example, Elnegamy et al. (2024) used a protocol with 15-minute RES sessions three times per week, whereas Justice et al. (2023) implemented a more intensive daily regimen of 30 min. Both approaches yielded positive results, suggesting that NMES can be effective across various intensities; however, the optimal parameters for maximizing functional recovery remain unclear. Furthermore, the diversity in outcome measures, with some studies focusing on muscle strength and others on functional recovery or electrophysiological markers, complicates direct comparisons and limits the ability to draw definitive conclusions regarding the most critical factors influencing treatment success.

The included studies demonstrated fair to high methodological quality when evaluated using the PEDro scale, suggesting a reasonable degree of robustness in their designs. However, potential biases may have been introduced due to certain methodological shortcomings, such as inadequate blinding and limited sample sizes, which could have affected the reported results. Despite these limitations, the consistently positive outcomes observed across various settings and protocols indicate that NMES shows considerable promise as a therapeutic approach for NBPP. To advance the field, it is crucial to establish standardized treatment protocols and outcome measures, enabling better comparisons between studies and facilitating the creation of evidence-based clinical guidelines.

Limitations

This review provides insightful perspectives on the potential benefits of NMES in managing NBPP; however, it is important to acknowledge certain limitations. The small sample sizes in the studies reviewed limit the generalizability of the findings to a wider population of infants with NBPP. Additionally, the considerable differences in NMES protocols across these studies, such as variations in stimulation parameters, session frequency, and treatment duration, complicate the development of standardized guidelines and the determination of the most effective therapeutic strategies. Furthermore, the predominantly short follow-up periods in these studies restrict our understanding of the long-term sustainability of the benefits of NMES. While some improvements were noted for up to three months, it remains unclear whether these benefits persist into later childhood, when functional demands increase.

Inadequate blinding in several studies also introduced performance and detection biases. These factors highlight the necessity for high-quality, transparent trials. Another limitation was the methodological quality of the included studies. Despite fair to high PEDro scores, many studies lacked essential elements, such as blinding of participants, therapists, and outcome assessors. This lack of blinding may introduce bias, as expectations from both participants and researchers could affect the reported outcomes. Moreover, the analysis was based on a small number of randomized controlled trials, with only three studies meeting the inclusion criteria, which weakened the overall evidence base. The possibility of publication bias should also be considered, as studies with positive results are more likely to be published, potentially skewing the review findings.

The risk of bias was considered across studies, particularly regarding potential publication bias. The limited number of studies included (n=3) affects generalizability, and selective reporting may have skewed the positive outcomes.

Recommendations for Future Research

Subsequent investigations should strive to overcome these constraints to bolster empirical support for NMES in treating NBPP. Implementing extensive multi-site randomized controlled studies would improve the applicability of the results and offer a more thorough understanding of the efficacy of NMES across various patient groups. These investigations should emphasize methodological excellence by incorporating appropriate randomization, allocation concealment, and blinding of subjects, therapists, and outcome evaluators to reduce potential biases. Extended follow-up periods are essential to assess the longevity of NMES-induced benefits and evaluate its influence on functional outcomes as children develop and encounter new developmental challenges.

Furthermore, establishing uniform NMES protocols, including stimulation variables such as frequency, intensity, pulse duration, and electrode positioning, would enable better study comparisons and aid in identifying the most effective treatment approaches. Future research should also delve into the underlying processes by which NMES promotes neuroplasticity and functional recovery in patients with NBPP. Comprehending these mechanisms could lead to refined therapy protocols and potentially the creation of novel, more potent interventions.

Beyond clinical outcomes, upcoming studies should examine the psychosocial effects of NMES on both infants and their families, as well as conduct cost-effectiveness evaluations to determine its viability for widespread clinical adoption. Comparative research exploring NMES alongside or in conjunction with other rehabilitation techniques, such as constraint-induced movement therapy or mirror therapy, could provide insights into integrated treatment strategies that maximize recovery. By addressing these research gaps, future studies can contribute to the development of evidence-based guidelines that support the effective and safe application of NMES in rehabilitating infants with NBPP.

Conclusions

This narrative review suggests that NMES, particularly RES, may benefit motor function and reduce muscle degeneration in infants with NBPP. However, the current evidence is based on a limited number of small-scale studies that have methodological constraints. Future research should emphasize standardized NMES protocols, robust study designs, and long-term follow-up to determine the clinical utility of NMES in routine NBPP rehabilitation.

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