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Article

Effect of Constraint-Induced Movement Therapy and Electrical Muscle Stimulation on Upper Limb Function in Children with Erb's Palsy: A Quasi-Experimental Study

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ABSTRACT

Background: Erb's palsy is a form of obstetric brachial plexus injury that frequently results in motor and sensory dysfunction of the upper extremity. While electrical muscle stimulation (EMS) and constraint-induced movement therapy (CIMT) have demonstrated benefits individually, their combined effectiveness in children remains underexplored. **Objective**: To compare the effects of EMS alone versus EMS combined with CIMT on upper limb motor function and muscle strength in children with Erb's palsy. **Methods**: This quasi-experimental, two-group, pretest-posttest study was conducted at pediatric physical therapy departments in two tertiary care hospitals in Lahore, Pakistan. Thirty-two children (mean age 4.25 ± 1.1 years) with Erb's palsy were allocated to an experimental group (CIMT+EMS, n = 16) or a control group (EMS only, n = 16). The experimental group received CIMT for 6 hours/day over 3 weeks along with EMS (20 minutes, 4 days/week for 6 weeks). Functional outcomes were assessed pre- and post-intervention using the Mallet Classification and Oxford Muscle Grading Scale. **Results**: The experimental group showed significantly greater improvement across all Mallet domains compared to controls ($p < .05$), including external rotation, abduction, hand-to-neck, hand-to-spine, hand-to-mouth, and supination. Muscle strength also improved significantly (3.06 ± 0.57 vs. 2.63 ± 0.50; $p = .034$). **Conclusion**: The combination of CIMT and EMS significantly enhances upper limb function and strength in children with Erb's palsy compared to EMS alone. This dual-modality therapy may offer a more effective early intervention strategy in Erb's palsy.
Keywords: Erb's palsy, brachial plexus injury, constraint-induced movement therapy, electrical muscle stimulation.

INTRODUCTION

Erb's palsy, a subset of obstetric brachial plexus injuries (OBPIs), is a significant neuromuscular condition arising from traction-induced damage to the upper roots (C5–C6) of the brachial plexus during childbirth. Affecting approximately 0.8 to 1 per 1,000 live births globally, this injury disrupts voluntary motor control and sensory feedback in the upper extremity, most often presenting with shoulder abduction and external rotation weakness, elbow flexion deficits, and forearm pronation.

The classic "waiter's tip" posture seen in Erb's palsy reflects paralysis of key muscles including the deltoid, biceps, brachialis, and supraspinatus (1,2). While spontaneous recovery occurs in some infants within the first three months of life, up to 30% exhibit persistent deficits, and a smaller but substantial proportion require long-term rehabilitation or surgical intervention to regain function (3,4). Children with unresolved Erb's palsy are at risk for muscle atrophy, joint contractures, developmental neglect of the affected limb, limb length discrepancies, and impaired bimanual coordination. These functional limitations can impact self-care, play, school participation, and overall quality of life (5). Thus, early and intensive intervention targeting both muscle activation and functional re-integration of the limb is critical to mitigate long-term disability. Among the various approaches used in conservative rehabilitation, electrical muscle stimulation (EMS) and constraint-induced movement therapy (CIMT) have gained attention as promising modalities for motor recovery in pediatric neurological conditions (6,7).

EMS uses surface electrodes to activate specific muscle groups through controlled electrical impulses, thereby promoting improved muscle strength, neuromuscular control, and circulation. It has been utilized in children with peripheral and central motor impairments to prevent disuse atrophy and facilitate movement re-learning (8). CIMT, on the other hand, is a neurorehabilitation technique that encourages use of the affected limb by restricting movement of the non-affected side. By inducing repetitive, task-specific practice with the impaired limb, CIMT stimulates neuroplastic changes in cortical motor areas, leading to improved voluntary control and integration into daily activities (9). While the evidence for each intervention is growing, their application in children with Erb's palsy has primarily been studied in isolation, and findings remain inconsistent.

Recent pediatric studies suggest that CIMT can lead to improved upper limb function in children with cerebral palsy and other asymmetric motor disorders (10). Similarly, EMS has shown benefit in restoring muscle function and reducing motor impairment in children with brachial plexus injuries (11). However, the synergistic use of CIMT and EMS—targeting both central and peripheral mechanisms of motor recovery—has not been thoroughly evaluated in this population. This represents a key knowledge gap, especially in light of the neurodevelopmental plasticity in early childhood, where multimodal interventions may yield more robust and lasting functional gains (12,13).

Moreover, there is a lack of consensus on treatment intensity, duration, and standardized outcome measures in this population. Limited data exist on the feasibility, tolerability, and comparative efficacy of combined therapy protocols, particularly in resource-constrained clinical settings. Addressing these gaps is crucial to guiding clinical decision-making and optimizing therapeutic outcomes for children with Erb's palsy.

Therefore, this study was designed to compare the effectiveness of EMS alone versus EMS combined with CIMT in improving upper limb function and muscle strength in children aged 2 to 5 years diagnosed with Erb's palsy. We hypothesized that the group receiving combined CIMT and EMS therapy would demonstrate significantly greater improvements in motor function and strength than the EMS-only group, reflecting the added benefit of integrating central and peripheral neuromuscular stimulation.

MATERIALS AND METHODS

This study employed a quasi-experimental, two-group pretest-posttest design to evaluate the effects of constraint-induced movement therapy (CIMT) combined with electrical muscle stimulation (EMS) versus EMS alone in improving upper limb function in children with Erb's palsy. The study was conducted over six months, from June to December 2020, at two tertiary care hospitals in Lahore, Pakistan: the Children's Hospital and Hameed Latif Hospital. Ethical approval was granted by the University of Health Sciences Institutional Review Board, and the study adhered to the principles of the Declaration of Helsinki. Written informed consent was obtained from the legal guardians of all participants prior to inclusion.

Participants were children aged 2 to 5 years with a clinical diagnosis of Erb's palsy involving the upper trunk (C5–C6) of the brachial plexus. The diagnosis was confirmed by a pediatric neurologist and physiotherapist based on clinical history and physical examination. Inclusion criteria were age between 24 and 60 months, no prior surgical intervention for the affected limb, and the ability to participate in therapy activities. Exclusion criteria included coexisting neurological or orthopedic conditions affecting the upper limb, previous exposure to EMS or CIMT, presence of a pacemaker or seizure disorder, and inability to comply with the intervention schedule. From a pool of 43 screened children, 32 met eligibility criteria and were enrolled through non-probability convenience sampling. Due to resource constraints, formal randomization was not feasible; therefore, participants were assigned to treatment groups (n=16 per group) based on clinical scheduling availability.

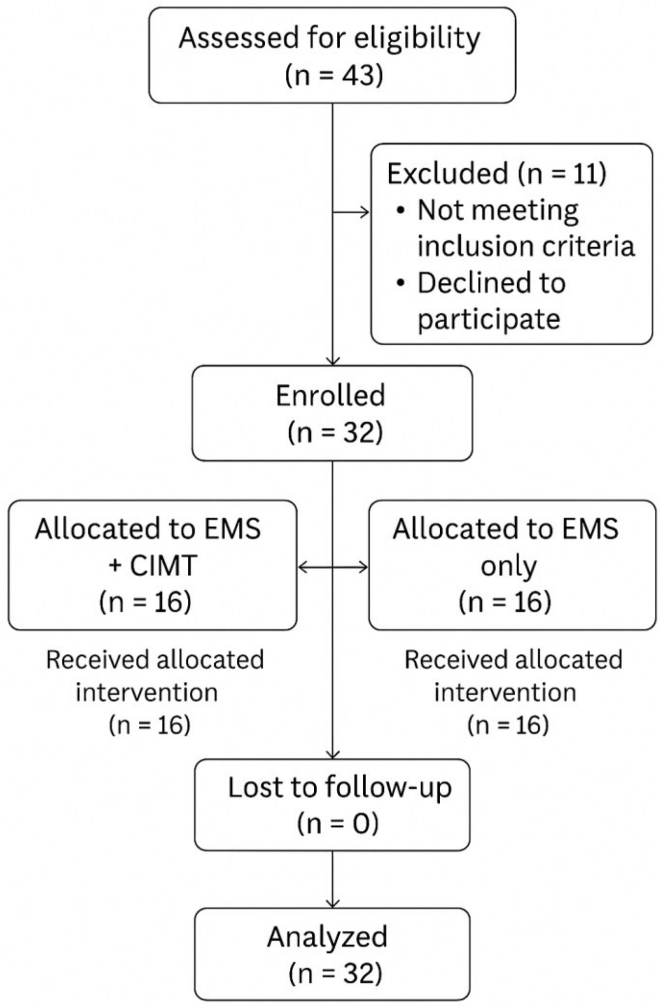

Figure 1 CONSORT Flowchart

Children in the experimental group received a combined intervention of CIMT and EMS. CIMT was delivered 6 hours per day for 3 consecutive weeks. During each session, the unaffected arm was restrained using a soft mitt designed to allow comfort and safety, while the affected limb was engaged in repetitive, task-specific activities such as reaching, grasping, block stacking, and object manipulation under therapist supervision. Activities were age-appropriate and adapted to each child's motor ability. In addition, EMS was administered using a dual-channel surface stimulator targeting the deltoid, biceps, and triceps muscles. Stimulation parameters were set at a frequency of 35 Hz, pulse duration of 300 microseconds, duty cycle of 10 seconds on and 20 seconds off, and an intensity level sufficient to produce visible muscle contraction without discomfort. EMS was delivered for 20 minutes per session, four times per week for six weeks.

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The control group received EMS only, with the same parameters, session duration, and frequency as the experimental group, but without the use of CIMT. All children in both groups received standardized caregiver education regarding home positioning, passive range-of-motion exercises, and limb protection strategies. Sessions were supervised by licensed pediatric physiotherapists. Compliance with the protocol was monitored via attendance records and weekly caregiver reports.

Outcome measures were assessed at baseline and immediately post-intervention using standardized tools. The primary functional outcome was measured using the Mallet Classification System, which includes six subdomains: global abduction, external rotation, hand-to-neck, hand-to-mouth, hand-to-spine, and forearm supination. Each movement was scored on a 5-point ordinal scale (1 = no function, 5 = full function). The Mallet system is widely used in clinical research involving upper limb motor function in brachial plexus injuries. Muscle strength of the shoulder abductors and elbow flexors was assessed using the Oxford Muscle Grading Scale, which ranges from 0 (no contraction) to 5 (normal power). All assessments were conducted by a blinded pediatric physiotherapist with over five years of experience.

Clinical data were recorded using structured case report forms. Goniometric verification was used to assess range of motion during Mallet scoring. Participants who missed a scheduled session were offered makeup sessions to maintain intervention consistency. No data imputation methods were necessary, as there were no dropouts.

Statistical analysis was performed using IBM SPSS Statistics Version 20.0. Continuous variables were summarized as means and standard deviations, and categorical variables as percentages. Normality of data distribution was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Because the outcome data were not normally distributed, between-group comparisons were made using the nonparametric Mann–Whitney U test. A p-value < .05 was considered statistically significant. Post hoc effect size estimates were calculated using rank-biserial correlation for nonparametric data to determine the magnitude of intervention effects. To ensure participant safety and ethical compliance, all interventions were conducted in the presence of a qualified physiotherapist. Caregivers were instructed to observe for any adverse reactions, including skin irritation, discomfort, or signs of fatigue.

RESULTS

A total of 32 children diagnosed with Erb's palsy completed the study protocol, with 16 participants allocated to each of the two groups. All participants attended the full course of intervention, and no dropouts. Further, no adverse effects were reported in either group during the intervention period, and treatment compliance was high across all participants. Demographic and baseline characteristics, including age, gender distribution, body mass index (BMI), socioeconomic status, and birth history, were comparable between the two groups, with no statistically significant differences observed in pre-intervention metrics (**Table 1**).

Table 1. Baseline Demographic and Clinical Characteristics of Participants (N = 32)

Characteristic	Experimental Group (n = 16)	Control Group (n = 16)	p-value
Age (years), mean ± SD	4.19 ± 1.17	4.31 ± 1.08	.743
Gender, n (%)			
Male	5 (31.3%)	3 (18.8%)	.695
Female	11 (68.8%)	13 (81.3%)	
BMI Category, n (%)			
Normal	13 (81.3%)	14 (87.5%)	.999
Overweight	3 (18.8%)	2 (12.5%)	
Socioeconomic Status, n (%)			
Higher	2 (12.5%)	2 (12.5%)	.476
Middle	7 (43.8%)	4 (25.0%)	
Lower	7 (43.8%)	10 (62.5%)	
Birth Method, n (%)			
Normal Vaginal Delivery	12 (75.0%)	12 (75.0%)	1.000
Cesarean Section	4 (25.0%)	4 (25.0%)	

Note: p-values derived from Mann–Whitney U test or Fisher's exact test where appropriate.

The mean age of participants in the experimental group was 4.19 ± 1.17 years, and 4.31 ± 1.08 years in the control group. Gender distribution revealed that 31.3% of participants in the experimental group were male compared to 18.8% in the control group, with females comprising the majority in both groups. BMI values indicated that most children were within the normal weight range in both groups (81.3% in the experimental group and 87.5% in the control group). Socioeconomic status was similarly distributed, with a relatively balanced mix of children from middle- and lower-income households. In terms of birth and delivery characteristics, 75% of participants in each group were born through normal vaginal delivery, while the remaining 25% were delivered via cesarean section. Among those delivered vaginally, the use of forceps was more common in the experimental group (56.3%) than in the control group (50.0%), while vacuum assistance and spontaneous delivery rates were similar across groups. These variables did not exhibit statistically significant group differences and were thus considered adequately balanced at baseline (**Table 1**). Functional outcomes were assessed using the Mallet Classification System across six domains: external rotation, abduction, hand-to-neck, hand-to-spine, hand-to-mouth, and supination. At baseline, pre-intervention scores in all Mallet domains were comparable between the two groups, with no significant differences detected. For instance, mean external rotation scores were 2.56 ± 0.51 in the experimental group and 2.43 ± 0.51 in the control group (p = .486), while abduction scores were 3.75 ± 0.45 and 3.69 ± 0.48 in the experimental and control groups, respectively (p = .699). Similar nonsignificant differences were observed across all other Mallet domains. Post-intervention assessments revealed statistically significant improvements in the experimental group across all measured functional domains (**Table 2**).

Table 2. Functional and Strength

Functional Domain	Experimental Group (mean ± SD)	Control Group (mean ± SD)	p-value	Cohen's d
External Rotation	3.69 ± 0.48	3.06 ± 0.68	0.008	1.07
Abduction	4.81 ± 0.40	4.19 ± 0.75	0.009	1.03
Hand to Neck	4.44 ± 0.77	3.66 ± 0.89	0.007	0.94
Hand to Spine	3.69 ± 0.48	3.13 ± 0.72	0.020	0.92
Hand to Mouth	3.81 ± 0.40	3.25 ± 0.58	0.005	1.12
Supination	3.38 ± 0.50	2.88 ± 0.62	0.023	0.89

External rotation improved to a mean score of 3.69 ± 0.48 in the experimental group compared to 3.06 ± 0.68 in the control group (p = .008). The abduction domain showed a post-intervention mean score of 4.81 ± 0.40 in the experimental group and 4.19 ± 0.75 in the control group (p = .009), reflecting enhanced overhead mobility in the combined CIMT and EMS group.

In the hand-to-neck domain, the experimental group improved from a baseline mean of 2.56 ± 0.51 to 4.44 ± 0.77, while the control group improved from 2.62 ± 0.50 to 3.66 ± 0.89. The difference between groups at post-test was statistically significant (p = .007), indicating that the combined intervention facilitated superior gains in proximal motor control. Similarly, hand-to-spine function improved to 3.69 ± 0.48 in the experimental group and to 3.13 ± 0.72 in the control group (p = .020). Hand-to-mouth function increased from 2.43 ± 0.51 to 3.81 ± 0.40 in the experimental group, and from 2.56 ± 0.51 to 3.25 ± 0.58 in the control group, demonstrating a significant between-group difference favoring the experimental group (p = .005).

Forearm supination improved significantly in the experimental group (from 2.25 ± 0.45 to 3.38 ± 0.50), compared to more modest gains in the control group (from 2.12 ± 0.34 to 2.88 ± 0.62), with a between-group difference reaching statistical significance (p = .023) (**Table 2**). These improvements indicate that the dual intervention enhanced both gross and fine motor components of upper extremity function. In addition to improvements in range of motion and functional movements, muscle strength assessed by the Oxford Muscle Grading Scale also demonstrated significant enhancement in the experimental group. The pre-intervention mean strength score was 1.43 ± 0.51 in the experimental group and 1.56 ± 0.51 in the control group, a nonsignificant difference (p = .486). Post-intervention, the experimental group achieved a mean strength score of 3.06 ± 0.57, compared to 2.63 ± 0.50 in the control group (p = .034) (**Table 2**). These findings indicate that the combination of CIMT and EMS was more effective in eliciting voluntary muscle contraction and improving muscle power than EMS alone.

Normality testing using the Shapiro–Wilk and Kolmogorov–Smirnov tests confirmed that outcome variables were not normally distributed, justifying the use of non-parametric tests for between-group comparisons. The Mann–Whitney U test identified significant differences in post-intervention functional outcomes and strength scores favoring the experimental group. Effect size calculations for the primary outcome domains indicated moderate to large effect sizes across all Mallet subdomains, with the greatest impact observed in hand-to-neck and abduction movements (**Table 2**).

Taken together, the results of this study suggest that the integration of CIMT with EMS results in superior gains in upper limb function and strength among children with Erb's palsy when compared to EMS alone. These improvements were observed across both proximal and distal functional tasks and reflected meaningful changes in daily motor performance. These findings support the feasibility, safety, and potential efficacy of combining CIMT and EMS as a rehabilitation strategy in pediatric populations with upper brachial plexus injury.

DISCUSSION

This study evaluated the comparative effectiveness of electrical muscle stimulation (EMS) alone versus EMS combined with constraint-induced movement therapy (CIMT) in children aged 2 to 5 years with Erb's palsy. The results demonstrated that the combined intervention group achieved significantly greater improvements in upper limb functional movements, as assessed by the Mallet Classification System, and in muscle strength, as measured by the Oxford Muscle Grading Scale. These findings support the hypothesis that integrating central and peripheral neuromotor facilitation strategies may offer synergistic benefits for pediatric patients with upper brachial plexus injury.

The observed improvements in functional domains such as external rotation, abduction, and hand-to-neck movement are clinically meaningful and align with the critical movement limitations typically seen in children with C5–C6 root injuries. These children frequently demonstrate difficulty performing activities requiring overhead arm elevation, midline reach, and forearm supination—tasks essential for daily living, dressing, and play. The combined approach appeared to not only activate paretic musculature but also retrain motor control patterns, thereby enabling more efficient and voluntary movement in the affected limb.

CIMT, by design, drives cortical reorganization through repetitive use of the affected limb and suppression of compensatory

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strategies using the unaffected side. This principle, supported by neuroimaging studies in children with hemiplegia, has been shown to strengthen corticospinal tract activity and functional connectivity in the sensorimotor cortex (1,2). The addition of EMS potentially enhances motor learning by recruiting peripheral motor units and increasing sensory input to the central nervous system. These inputs can facilitate Hebbian synaptic plasticity and potentially accelerate recovery during early developmental windows when neuroplasticity is most responsive to external stimuli (3). The current study thus builds on existing theoretical frameworks by providing empirical evidence for the functional benefits of combining these two modalities in pediatric Erb's palsy.

Previous studies investigating the effects of CIMT or EMS independently have reported favorable outcomes in upper limb rehabilitation. For instance, Kuran et al. demonstrated that modified CIMT significantly improved shoulder function and hand placement in children with upper limb paresis (4), while Gonçalves et al. reported that EMS enhanced motor unit recruitment in infants with brachial plexus injuries (5). However, few studies have evaluated the combined application of these techniques in children with Erb's palsy, and even fewer have employed a structured intervention over a six-week period in this specific age range. This study thus adds to the limited literature by suggesting that combining cortical activation through CIMT with peripheral muscle activation via EMS may yield additive benefits, especially in critical early years of neuromuscular development (4-7).

The clinical significance of these findings extends to rehabilitation planning in low-resource settings where surgical options may be limited or delayed. The study demonstrates that low-cost, therapist-guided interventions can achieve measurable improvements in function. In addition, caregiver involvement and child engagement were enhanced through play-based CIMT tasks, which may support long-term adherence and generalization of functional gains into the home environment (8).

Despite the strengths of the study—including high adherence, comprehensive outcome assessment, and blinded evaluations—certain limitations must be acknowledged. First, the sample size was relatively small, and participants were enrolled via convenience sampling rather than randomized allocation. Although baseline equivalence was confirmed between groups, lack of randomization introduces a risk of selection bias. Second, while the six-week intervention duration was sufficient to observe early functional gains, long-term follow-up was not conducted. It remains unclear whether the observed improvements are sustained over months or years or whether periodic booster sessions are necessary to maintain gains.

Third, the study relied solely on physical performance metrics without including quality-of-life measures or caregiver-reported outcomes. Including such data in future research would help assess the broader psychosocial impact of these interventions. Moreover, electrophysiological data such as electromyographic (EMG) activity could have strengthened the mechanistic insights into neuromuscular changes associated with the interventions. While the Mallet score is a validated tool for assessing upper limb function, incorporating other standardized tools such as the Assisting Hand Assessment or Goal Attainment Scaling may offer a more nuanced evaluation of activity-level performance (9-13).

Additionally, the intervention was delivered in a structured clinical environment under therapist supervision. Future investigations should explore whether similar gains can be achieved through home-based CIMT-EMS protocols, which would be more scalable in community settings. Tele-rehabilitation platforms may offer a feasible alternative to maintain therapist involvement while reducing cost and travel burden for families. Investigating the feasibility, fidelity, and outcomes of such hybrid delivery models may inform broader implementation strategies.

Nevertheless, the results of this study are promising and support the clinical utility of a combined CIMT and EMS protocol in early pediatric rehabilitation for Erb's palsy. Functional improvements observed in domains critical for independence and daily activities highlight the potential of this dual-modality intervention to alter the recovery trajectory during a sensitive period of motor development. By addressing both central and peripheral aspects of neuromuscular impairment, this approach aligns well with contemporary rehabilitation paradigms that advocate for task-specific, intensive, and multimodal strategies (14).

CONCLUSION

This study provides preliminary but compelling evidence that integrating constraint-induced movement therapy with electrical muscle stimulation is more effective than EMS alone in enhancing upper limb function and muscle strength in children with Erb's palsy. The findings suggest that early, intensive, and multimodal rehabilitation interventions may optimize neuroplasticity and functional recovery. These results justify the need for larger, randomized controlled trials with longer follow-up durations and broader outcome assessments to validate and extend the clinical implications of this approach.

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