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Contribution of reciprocal electrical stimulation across elbow muscles to motor recovery of infants with Erb's Palsy: A randomized controlled trial

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ABSTRACT

This study examined the effect of reciprocal electrical stimulation (RES) across elbow flexors and extensors on the reaction of degeneration percentage and motor function in Erb's palsy infants. Forty infants with Erb's palsy aged between 2-5 months were randomly allocated to one of two equal groups: the control group (A) received standard physical therapy, the study group (B) received traditional physical therapy plus a 15-minute RES through elbow flexors and extensors. For three months, interventions were carried out three times each week. The percentage of reaction of degeneration and motor function were assessed pre- and post-treatment using electromyography and Toronto active motion scale respectively. There was a significantly greater reduction in the percentage of reaction of degeneration and increase in the Toronto active motion scale score in the study group (B) as compared to the control group (A) ($p < 0.001$, $p = 0.007$ consequently), indicating more improvements following the RES application. Incorporating the RES in the traditional rehabilitation programs for Erb's palsied infants is likely effective in improving motor functions. It is advisable for the pediatric physical therapist to consider such a therapeutic approach in caring for those infants.

KEYWORDS

Brachial Plexus Birth Injury; Neuromuscular Electrical Stimulation; Active Motion; Electroneuronography; Motor Function

1. INTRODUCTION

The brachial plexus is a network of peripheral nerves that emerges from the upper and lower dorsal cords. These nerves act as electrical wiring, carrying orders from the brain to the arm musculature and sensory information to and from the shoulder, elbow, wrist, and hand muscles (Ackland et al., 2008). High-intensity trauma to the neck and upper limb, especially when the head and neck are abruptly pushed away from the ipsilateral shoulder or when the infant is pulled off the raised arm, can harm the brachial plexus and more severely damage the lower cervical plexus (Alfonso, 2011).

Damage to the upper limb may cause partial or total paralysis, the severity of injury will impact whether the patient will be paralyzed permanently or temporally (Mooney & Ireson, 2009). Worldwide, the prevalence of brachial plexus injuries varies between 0.2 and 4% of live births; in the United States, it is 1.5%, in the United Kingdom and Republic of Ireland, it is 0.42%, and in other Western nations, it is 1 to 3 per 1000 live births (Dunham, 2003). The upper arm type (Erb's palsy) injury is restricted to the C5,6 nerve roots, with C7 affection in certain cases or C8 and T1 nerve roots are involved in lower-arm type (Klumpk's paralysis), or avulsion of all brachial plexus roots from the spinal cord (whole-arm type) (Li et al., 2023).

Many patients are left with some weakness at shoulders, elbow a forearm level (Alexander & Mathews, 2010). The newborn's arm is held in the position of a waiter's tip, which involves flexing the wrist and extending the arm inside. Elbow flexor contracture has been recorded in 48 to 70% of children with OBPI (Sheffler et al., 2012). The underlying mechanism and cause of elbow flexion contracture in OBPI are yet unknown. One possible explanation for these observations is that elbow flexor innervation returns before elbow extensor innervation, resulting in flexion dominance over extension function for a period of time, resulting in an imbalance in flexor and extensor performance (Ho et al., 2010). Previous studies have demonstrated the potential advantages of neural electrical stimulation of the muscles for children with brachial plexus injury (Okafor et al., 2008).

A neuromuscular electrical stimulation method called reciprocal electrical stimulation alternately stimulates the motor units of agonist and antagonist muscles. The firing patterns of healthy muscles may often be mimicked by the RES pattern. Additionally, it has been speculated that the RES stimulation pattern will strengthen the antispastic muscle and decrease the cortical excitability of the spastic muscle while increasing neural drive by activating the sensory receptors and sensory neurons in the agonist and antagonist muscles (Elnaggar & Elbanna, 2019).

There exists only one study that explored the effect of RES in a sample of children with OBPI who were aged 1-3 years and reported significant improvement in motor function (Abdelaziz et al., 2022). Thus, the evidence from a single study might not be sufficient to prove the effectiveness of RES in this patient population. In addition, the study mentioned above was limited to a specific age group who were 1-3 years after injury while the current study aimed to investigate the early use of RES on infants immediately after the beginning of lesion (2-5 months), which might improve the likelihood of achieving more positive outcomes (Elnaggar, 2020).

Thus, the aim of the current study is to find out how RES affected joint mobility, muscular power, and neurological repair (percentage of degeneration) in infants with OBPI. We predict that early intervention using RES will lead to better results.

2. METHODS

2.1. Study Design

This was a randomized controlled trial that was carried out at Prince Sattam bin Abdulaziz University, College of Applied Medical Sciences outpatient clinic in Alkharj, Saudi Arabia. The protocol was reviewed by the Research Ethics Committee in Department of Physical Therapy and Health Rehabilitation granted the following approval number (RHPT/023/011). The study procedures were in accordance with the ethical standards of Declaration of Helsinki 1975. The study procedures, benefits, and potential risks were thoroughly explained to the legal-guardians who signed a consent form before enrollment. A single-blind design was adopted, where the examiner was not aware of the treatment allocation.

2.2. Participants

Forty children with OBPI took part in the present study. Inclusion criteria were infants with OBPI limited to nerve roots C5, C6, with/without involvement of C7, partial lesion as determined by electrophysiological examinations, age between two to five months, and willingness of the infant’s family to take part in the study. Exclusion criteria were infants with clavicular or humeral fractures, complete transection of nerve roots, other neurological co-morbidities such cerebral palsy, congenital musculoskeletal deformities, or recommendation against electrical stimulation by the attending neuro-pediatrician.

2.3. Randomization

Eligible children were randomized into two groups by an independent researcher. A simple randomization was performed, participants were assigned a number from 1-40 and an online randomizer (https://www.randomizer.org/#randomize) was used to create two sets. Children whose numbers fell in the first set received the traditional physical therapy program (control group) and those whose numbers fell in the second set received the same program in addition to the RES (study group).

2.4. Sample size

A preliminary power analysis was conducted using G-Power software (version 3.1.9.2, Dusseldorf, Germany) to identify the required sample size. The analysis was based on estimates of two independent means and common standard deviation of reaction of degeneration percentage of biceps brachii muscle (mean A = 56.43, mean B = 48.92, common SD = 7.42), which were obtained from a pilot study. A total sample size of 34 infants (17 per group) was required assuming an alpha level of 0.05 and power of 80%. However, the sample size was increased to 40 infants (20 per group) to account for the possible dropout rates.

2.5. Intervention

2.5.1. Traditional physical therapy

Participants in group A and B received a traditional physical therapy program three times a week, for three successive months. Each session lasted for approximately 30 minutes and composed of the following: 1) Massage (spiral effleurage, longitudinal and transverse thumb effleurage for 5 minutes or until hyperemia), 2) Facilitation of muscle contraction through a variety of tactile and proprioceptive stimulation techniques – this was applied for the shoulder flexors, abductors, and external rotators, elbow flexors, and wrist/finger extensors. In patients whose lesion extend to involve C7, the facilitation techniques were also applied to elbow extensors. 3) Weight-bearing exercise, considering the developmental milestone (prone forearm support, prone full hand support). 4) Range of motion exercises – all joints of the affected side were moved through the full range of motion. 5) Sucking exercise.

2.5.2. Reciprocal Electrical Stimulation (RES)

A computerized electrical stimulator (Vectra®2C; Chattanooga, TS, USA) with a dual-channel stimulating unit was used, each channel had two adhesive small-size (1.5 cm in diameter) carbon rubber electrodes.

The patient was positioned in supine lying position with the affected arm beside the body and elbow extended, the skin over the anterior and posterior comportment of the upper arm was cleaned using medical cotton sacked in alcohol before placing the fore stimulating electrodes.

The first two stimulating electrodes for the biceps muscle were placed at the superior and inferior 1/3 of anterior surface of the upper arm with a distance in between the two electrodes at least the size of one of them, while the other two electrodes for the triceps muscle were placed at the superior and inferior 1/3 of the posterior surface of the upper arm.

One millisecond pulse duration and a frequency of 50Hz with a rectangular shaped pulse were utilized and stimulation was applied for 15 minutes. At first a low-intensity current is applied and gradually increased till a gentle contraction of the muscles appears and allow time for the child to become accustomed to the current and maintained sufficient and observable contraction.

2.6. Outcome measures

2.6.1. Percentage of degeneration (RD)

Surface electrodes were used in a computerized electromyographic device (Neuro screen plus four channel-version, TOENNES 97204 Hochberg, Germany) to calculate the percentage of degeneration of the biceps and triceps brachii muscles.

The patient was laid on their back on the examination table in a supine alignment, with their waist and trunk uncovered. To lessen skin resistance, medical cotton soaked in alcohol was used to clean the stimulating and recording areas. To prevent the arousal of any primal reflexes that may change the distribution of tones throughout the body, the infant's head was kept in a neutral position (Bonham & Greaves, 2011). Initially, the unaffected side underwent electroneurography, followed by the affected side. To create the compound muscle action potential, a bipolar stimulating electrode was placed manually above Erb's point. The reference recording electrode was placed farther away on a comparatively quiet spot, whereas the active recording electrode was placed on the motor point of the biceps muscle, which is the muscular mass anteriorly at the mid-arm level. The reference recording electrode was placed further distal on a reasonably calm area, while the active electrode was placed on the triceps muscle's motor point, which is the muscular mass posteriorly at the mid-arm level. The ground electrode was put on the top dorsal spine between the two scapulae. A 1 Hz frequency and 5 ms time basis were used to create a rectangular pulse. The strength of the stimulating current was gradually raised until there was no further rise in the amplitude of the diphasic myogenic compound action potential. A 10% increase in current was given to assure supramaximal stimulation. The level of stimulation ranges from 15 to 40 mA. The Neuro screen plus system's software was used to calculate the peak-to-peak amplitude. The following equation was used to compute the percentages of degeneration (Ahn et al., 2018).

$$\text{Percentage of degenerated fibers}$$

$$= 100\left(\frac{\text{Amplitude of evoked response (in } \mu \text{v) affected side}}{\text{Amplitude of euoked response (in} \mu \text{v) Normal side}} \times 100 \right)$$

2.6.2. Motor recovery

The motor recover was assessed using Toronto active motion scale (TAMS). For the purpose of this study, scores for elbow flexion and extension were recorded.

For good evaluation of OBPI infants nerve injury extent is TAMS for immediate and after surgery measurement tool of motor recovery. It consists of 15 movements of the upper limb joints, assessed using an eight-point scale to measure the strength of these movements. This is done by first evaluating the range of motion at each joint with gravity eliminated, followed by measuring the range of motion against gravity. Scoring of the TAMS is defined in Table 1 as follows (Abzug & Kozin, 2014):

Table 1. The grading system of Toronto Active Motion Scale

Observation **Gravity elimination**	**Muscle grade**
No muscle contraction	0
Contraction, no movement	1
Motion < $1/2$ range	2
Motion > $1/2$ range	3
Full range of movement	4
Against gravity	
Motion < $1/2$ range	5
Motion > $1/2$ range	6
Full range of movement	7

2.7. Statistical analysis

Statistical analysis was conducted using SPSS v20 (SPSS, INC, Chicago, IL). Normality of the data was assessed using Shapiro Wilk test and Leven's test of equality. Wilcoxon signed-rank test was applied to assess changes within each group and Mann Whitney U test to assess the difference between both groups. The level of significance was set at $p < 0.05$ for all statistical tests.

3. RESULTS

Fifty-seven children were initially screened and 40 of them were enrolled and randomized into the study groups. Three children (two children from group A and one child from group B) either did not complete the treatment or got lost during post-treatment measurements for unknown causes. The missing post-treatment data were substituted by carrying forward the pre-treatment observations and were included in the analysis. As demonstrated in Table 2, there were no significant differences between the study groups regarding their ages, weights, heights, sex, and their affected side at the baseline ($p>0.05$).

Table 2. Subjects' baseline characteristics

		Group ^{a} (n=20)	**Group** ^{b} (n=20)	***p*-value**
Age (months)		2.87 ± 0.71	2.99 ± 0.90	0.628
Weight (kg)		5.32 ± 1.42	5.11 ± 1.37	0.318
Sex, n (%)	Boys	9 (45 %)	13 (65 %)	0.341
	Girls	11 (55 %)	7 (35 %)	
Affected Side, n (%)	RT	6 (30 %)	8 (40 %)	0.741
	LT	14 (70 %)	12 (60 %)	

[a] *p-value of independent t-test*
[b] *p-value of Fisher exact test*

Table 3 shows that there was no significant difference between both groups in terms of the RD of biceps (p = 0.157) and triceps (p = 0.445) muscles before intervention. However, the post-treatment outcomes showed significant differences in both the RD of biceps and triceps muscles in favor of group B (p<.001). The comparison of the pre-, and post-treatment mean values of the RD in both groups demonstrated significant changes [biceps (Group A: p = 0.0003; Group B: p < .001), triceps (Group A: p = 0.0008; Group B: p = .0001)].

Table 3. Changes in the percentage of reaction of degeneration in biceps and triceps muscles for the study groups

	Group A (n=20)	**Group B** (n=20)	***z*-value**	***p*-value**
RD biceps muscle				
Pre	64.47 ± 4.19	63.35 ± 3.49	- 1.434	0.157
Post	57.84 ± 3.86	49.84 ± 6.87	- 3.464	< .001*
z-value	- 3.435	- 3.920		
p-value	0.0003*	< .001*		
RD triceps muscle				
Pre	62.37 ± 3.10	61.31 ± 4.41	- 3.920	0.445
Post	56.84 ± 4.56	48.79 ± 2.10	- 4.370	< .001*
z-value	- 3.920	- 3.883		
p-value	0.0008*	0.0001*		

Note. RD: reaction of degeneration; Data are presented as $\bar{X}$ *± SD; *Significant at p<0.05*

As demonstrated in Table 4, the comparison of the pretreatment TAMS scores for biceps (*p* = 0.820) and triceps (*p* = 0.779) muscles between both groups indicated non-significant differences. Whereas the post-treatment comparison indicated significant differences in both the biceps (*p* = 0.0007) and triceps (*p* = 0.0009) scores in favor of group B (*p*<0.05). The comparison of the pre- and post-treatment TAMS scores indicated significant differences in both groups [(Group A: *p* = 0.0008; Group B: *p* = .0001), triceps (Group A: *p* = 0.0005; Group B: *p* < .001)].

Table 4. Changes in the TAMS for biceps and triceps muscles for the study groups

	Group ^{a} (n=20)	**Group** ^{b} (n=20)	***z*-value**	***p*-value**
TAMS biceps muscle				
Pre	2 (2 – 3)	2 (2 – 3)	-0.251	0.820
Post	3 (3 – 4)	4 (3.25 – 5)	-2.910	0.007*
z-value	-3.360	-3.888		
p-value	0.0008*	0.0001*		
TAMS triceps muscle				
Pre	2 (2 – 3)	2 (2 – 3)	-0.329	0.779
Post	3 (3 – 3.75)	4 (3 – 4.75)	-2.869	0.009*
z-value	-3.494	-3.946		
p-value	0.0005*	< .001*		

*Note. TAMS: Toronto active movement scale; Data are presented as median (interquartile range); *Significant at p<0.05*

4. DISCUSSION

The aim of the present study was to investigate the effect of reciprocal stimulation of elbow flexors and extensors in contribution with traditional physical therapy program on percentage of degeneration and motor recovery in children with Erb's palsy. The findings revealed a significant reduction in the percentage of reaction of degeneration and increase in motor recovery of the biceps and triceps muscles in group B, suggesting that incorporation of RES into the treatment program for such children has the potential to enhance motor functions.

Until date, the management of OBPI has been insufficiently resolved. The recovery and management quality investigations showed that the majority of OBPI resolve spontaneously, with 92% of the restoration occurring within the first three months (Rouse et al., 1996). Nevertheless, spontaneous recovery should not be awaited especially since contractures & deformities may develop if the intervention is delayed (Abid, 2016). This may explain why this study thought about the early application of RES alongside physical exercises.

Studies on the role of RES for children with OBPI are very limited. We were able to reach only a single study by Abdelaziz et al. (2022), who applied the RES on biceps/triceps muscles for 20 minutes, three sessions/week for three successive months in a sample of children with Erb’s palsy who were 1-3 years and reported significant improvement in functional recovery (based on pre-to-post changes in the reaction of degeneration percentage). The results of this study may, therefore, substantiate those reported by Abdelaziz et al. (2022) but from younger sample (i.e., children aged 2-5 months).

Although, the mechanism by which the RES improved the motor functions is beyond the scope of this study, some possible explanations may apply. The most likely explanation is that RES causes a temporary increase in muscle metabolism and blood flow, facilitates the formation of additional spinal motor neuron pools, and stimulates blood flow to atrophied muscles in order to supply the growth factors and nutrients necessitated to improve muscle structure and function. These effects are similar to those of voluntary muscle contraction. It is believed that RES gives muscles proprioceptive input, which enables them to contract and become more active. Consequently, as RES goes on, more muscle fibers are activated and contracted (Badawy & Ibrahim, 2015). Also, neuromuscular adaptation and RES induced changes in the synchronous activation pattern are learned in brain by repeated stimulation manifested as improvement of motor function (Elnaggar & Elbanna, 2019).

Additionally, exercise may have also contributed to that motor recovery. Exercise (flexibility and muscle reinforcement) helps in minimizing the development of secondary and tertiary deformities, and augmenting week muscles, thus reducing impairment levels and keeping those muscles more active (Taeusch et al., 2005; Nath, 2006).

The results of this study should be interpreted considering the following limitations. First, the sample was limited to a specific age group (2-5 months), so it cannot be confirmed whether the current results are applicable to younger/older children. Second, the RES was applied to a single pair of muscles (i.e., biceps and triceps muscles), thus it would not be possible to indicate if application to different muscle pairs can induce comparable effects. Third, this study did not assess the outcome measures at the long term (after the RES was no longer administered to the children), so the sustainability of the effects beyond the post-treatment occasion cannot be guaranteed. Therefore, additional studies which consider recruiting larger sample representatives of different age groups, applying the RES on different muscle pairs, and assessing the outcome measures at a 3-6-12-month interval post-treatment are needed.

5. CONCLUSIONS

Based on the results of this study, incorporating the RES into the physical therapy program has the potential to enhance motor recovery of the upper limb in Erb’s palsy infants. Further research, however, is needed to support the reported evidence.

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ETHICAL APPROVAL

No. RHPT/023/011, approved by Prince Sattam bin Abdulaziz University, Department of Physical Therapy and Health Rehabilitation.

INFORMED CONSENT

Informed consent was signed and obtained from all parents involved in the study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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