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Use of Neuromuscular Electrical Stimulation in the Treatment of Neonatal Brachial Plexus Palsy: A Literature Review

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Use of Neuromuscular Electrical Stimulation in the Treatment of Neonatal Brachial Plexus Palsy: A Literature Review

Abstract

Background: The purpose of this study was to conduct a review of current literature on the effectiveness of neuromuscular electrical stimulation (NMES) for restoring motion and function in neonatal brachial plexus palsy (NBPP).

Method: A database search was conducted for NMES articles published between 1947 and 2015. Pre and posttreatment data were extracted for muscle power, active range of motion (AROM), and morphometric measurements.

Results: An initial search yielded 2,721 articles. A further title/abstract review produced 27 articles; of these, four met the inclusion criteria. Treatment protocols varied. There were no changes in average Medical Research Council (MRC) scores following treatment for elbow flexion, shoulder abduction, or wrist extension. Shoulder flexion increased from MRC 1 to 4. AROM improved following treatment.

Conclusions: Evidence for improved muscle strength after NMES is mixed. Improvement in AROM is more consistent. Due to variations in treatment modalities, patient profiles, and adjunct treatment, a clinical trial to isolate the effects of NMES in NBPP is required. Since improved motion and function has been reported, NMES in NBPP therapy remains reasonable.

Comments

The authors report no conflicts of interest to disclose.

Keywords

neonatal brachial plexus palsy, neuromuscular electrical stimulation, peripheral nerve injury, systematic review

Credentials Display and Country

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Occupational therapists and physical therapists often use modalities in the treatment of individuals with muscular weakness. Neuromuscular electrical stimulation (NMES) is a modality that involves the application of electrodes connected to a device that provides electrical current to a partially or completely denervated muscle with the goal of promoting functional recovery (Knutson, Fu, Sheffler, & Chae, 2015). The results of NMES in treating completely denervated muscle are inconsistent (Haastert-Talini & Grothe, 2013). NMES should be distinguished from other forms of electrical stimulation, such as transcutaneous electrical nerve stimulation (TENS). TENS targets nerve rather than muscle, and the goal of treatment is primarily pain relief, or in certain cases, spasticity mitigation (Karakoyun, Boyraz, Gunduz, Karamercan, & Ozgirgin, 2015). Refinements in the optimization of equipment settings have led to more promising results with improved motor unit recruitment (Woodcock, Taylor, & Ewins, 1999).

NMES has been used by therapists in the rehabilitation of multiple central neurological conditions, including stroke, cerebral palsy, and spinal cord injury, with demonstrable success (Giszter, 2008; Kerr, McDowell, & McDonough, 2004; Pomeroy, King, Pollock, Baily-Hallam, & Langhorne, 2006). The evidence for its effectiveness in treating peripheral nerve injury is less robust. Positive results have been reported mostly in the context of partial nerve injuries (Haastert-Talini & Grothe, 2013; Woodcock et al., 1999). In a recent randomized study comprising patients with severe median nerve compression, the group treated with postoperative electrical stimulation demonstrated improvements in functional outcomes as compared to the control group (Gordon, Sulaiman, & Ladak, 2009).

Despite the widespread use of NMES, there are no standardized protocols for its use in treating peripheral nerve injury. NMES involves the application of electrical current to muscles with the goal of promoting recovery following nerve injury. Through a systematic selection of frequency, pulse duration, electrode placement, and amplitude, among other parameters, a current is delivered to affected muscle groups. There is tremendous variation in settings, length of treatment, equipment, electrode placement, and adjunct therapies (Adedeji & Oyelese, 2009; Al-Majed, Neumann, Brushart, & Gordon, 2000; Cummings, 1985; Eng, Koch, & Smokvina, 1978; Woodcock et al., 1999). Evidence for the effectiveness of NMES in treating peripheral nerve injury (in particular, severe or complete injury) remains disparate. In particular, there is no standardized use of NMES in patients with neonatal brachial plexus palsy (NBPP). NBPP occurs as often as 3 per 1,000 live births. The stretch of brachial plexus nerves causes weakness or paralysis of the arm. Although the majority of affected infants recover spontaneously, depending on the severity and extensiveness of the palsy, conservative treatments (therapy or NMES) or surgical interventions are suggested. A detailed algorithm for NBPP management is published elsewhere (Somashekar, Di Pietro, Joseph, Yang, & Parmar, 2016). The purpose of this study was to review the literature in order to evaluate the effectiveness of NMES along with other concurrent treatments in restoring function in patients with NBPP.

Method

Literature Review

An Institutional Review Board (HUM75336) approved this study. We performed a review of the literature for English language articles published between January 1947 and March 2015 using the MEDLINE, EMBASE, and SCOPUS databases to retrieve citations regarding NMES. Brachial plexus palsy is a kind of peripheral nerve injury; therefore, we included both peripheral nerve and brachial plexus in the search terms to ensure all potential articles were included in the review process. Key search terms included peripheral nerve OR brachial plexus AND stimulation AND neuromuscular OR muscle OR electrical. Using the inclusion and exclusion criteria described below, we conducted a title and abstract search to identify relevant articles of interest. To ensure that the search was comprehensive, we performed a manual reference check in addition to the original search.

Inclusion and Exclusion Criteria

Included articles reported on human subjects with NBPP treated by NMES with description of primary outcomes and were published between January 1947 and March 2015 in the English language. We deemed articles that featured NMES in conjunction with other forms of treatment, such as massage, exercise, splinting, or complementary medicine, suitable for inclusion.

We excluded articles from review if they pertained to nontreatment data from animals, cadavers, anesthetic techniques, or radiographic or neurophysiological studies. In addition, we excluded intraoperative stimulation studies or articles that focused on irrelevant "electrical" modalities or nonperipheral nerve injury diagnoses. In particular, such modalities included TENS used primarily for pain relief. We excluded inappropriate diagnoses, such as central nervous system conditions and lower extremity peripheral nerve injuries. Two independent researchers reviewed each article and, when necessary, a third individual was consulted to reconcile any disagreements. Although we excluded animal data from analysis, we used these data in the discussion to support the human data findings.

Data Extraction and Analysis

After completing our formal article review, we extracted and examined data representing patient demographics, reported conditions, NMES equipment type and settings, and other concurrent treatments, where applicable. We also extracted pretreatment and posttreatment data regarding muscle power, active range of motion (AROM), and morphometric measurements to gauge the effectiveness and safety of NMES in the restoration of movement function. Muscle power refers to the degree of engagement and strength of the muscle, ranging from Medical Research Council (MRC) score of *M0* (no contractions) to *M5* (full movement against significant resistance), as categorized in the Appendix. AROM is the measure of patient-initiated angular movement in space around the joint of interest. Morphometric measurements refer to arm length and circumference. We included morphometric measurements as indicators for patients' muscle bulk status. To facilitate study comparison, AROM was converted to an MRC score in cases where muscle power was not directly reported, using the scale described in the Appendix.

Statistical Analysis

While case reports and case series provided most of the data, we included the highest possible level of evidence. Patient demographics and descriptive statistics are summarized in Table 1. We calculated mean values and standard deviations for AROM. In regard to morphometric parameters, we calculated pretreatment and posttreatment measurements as a percentage of the unaffected limb in the cases in which unaffected arm measures were explicitly reported.

Results

Article Retrieval and Characteristics

The initial article capture totals and subsequent attrition via the exclusion criteria are delineated in Figure 1. Our initial search yielded 2,721 articles. Further title and abstract review produced 27 articles for formal review. Of these 27 articles, four articles met the inclusion criteria. These four articles were published in the United States, India, and Nigeria and consisted of three case reports and one case-control study comprising eight cases.

Patient Demographics and Treatment Characteristics

Patient demographics and treatment characteristics are described in Table 1. There were 11 patients in the four studies with a mean age range of 2 weeks to 4 and a half months. All of the patients had NBPP, with one case of bilateral brachial plexus palsy (noted as two patients from the report by Adedeji and Oyelese [2009] in Table 1 for purposes of analysis). These NBPP cases comprised primarily upper brachial plexus injury (10 patients) with one case of global (C5-T1) palsy.

There was notable variation among the studies in equipment settings for electrical stimulation. There were widely ranging differences noted in pulse duration (0.1 ms to 1000 ms), as well as types of currents used, including a faradic and galvanic combination in one case. The stimulation period ranged

from 5 min to 15 min per muscle, while the overall length of treatment varied from 1 to 4 months. Three of the four studies included adjunct treatment along with electrical stimulation, including ROM exercises, splinting, soft tissue massage, constraint-induced movement therapy, and ayurvedic therapy.

Muscle Power

There was no change in average MRC score following treatment for elbow flexion, shoulder abduction, or wrist extension (see Table 2). Shoulder flexion increased from MRC 1 to 4.

AROM

AROM improved in all of the patients following treatment (see Table 2). Shoulder abduction increased from an average of 26 to 63 degrees, while shoulder flexion increased from 150 to 180 degrees. Elbow flexion increased from 10 degrees pretreatment to 51 degrees posttreatment, while wrist extension increased from eight to 46 degrees.

Morphometric Parameters

Arm length in one patient increased from 24 to 28.5 cm over the course of 28 days of treatment, with the initial arm length/unaffected arm percentage increasing from 98.7% pretreatment to 100% posttreatment (see Table 3). Arm circumference in one patient increased from 13.5 to 14.8 cm over the course of 28 days of treatment, with the initial arm length/unaffected arm percentage increasing from 98.5% pretreatment to 100% posttreatment. For the eight patients in the case-control study, the average arm circumference increased from 15 to 17 cm over the course of 6 weeks of treatment.

Table 1

Patient Demographics

Author & Year	No. Patients	Female	Country	Lesion	Prior Surgical Treatment	Mean Age at Treatment	Equipment	Settings	Other Treatment
Adedeji & Oyelese, 2009	2*	2*	Nigeria	C5-C7	No	3 weeks	Enraf-Nonius	8.5 mA to 15 mA Pulse duration: 1000 ms Pulse width: 300 ms 15 min per muscle	Yes; exercise, splint, soft tissue massage, two sessions/ week for 4 months
Berggren & Baker, 2015	1	1	United States	C5-T1	No	6 weeks	Not reported	20-25 pps Pulse duration: 0.1-0.15 ms	Yes; exercise, stretching, kinesiotaping, splints, constraint-induced movement therapy, nerve transfer surgery at 3 months
Okafor et al., 2008	8	5	Nigeria	C5-C6	No	22 days	707 model	Three sessions/week for 6 weeks	No
Srilakshmi & Chaganti, 2013	1	1	India	C5-C7	No	4.5 months	Not reported	Faradic and galvanic currents, 5 min per muscle	Yes; ayurvedic treatment, three sessions in 28 days

Note. *For purposes of analysis, one case of bilateral neonatal brachial plexus palsy is shown as two patients.

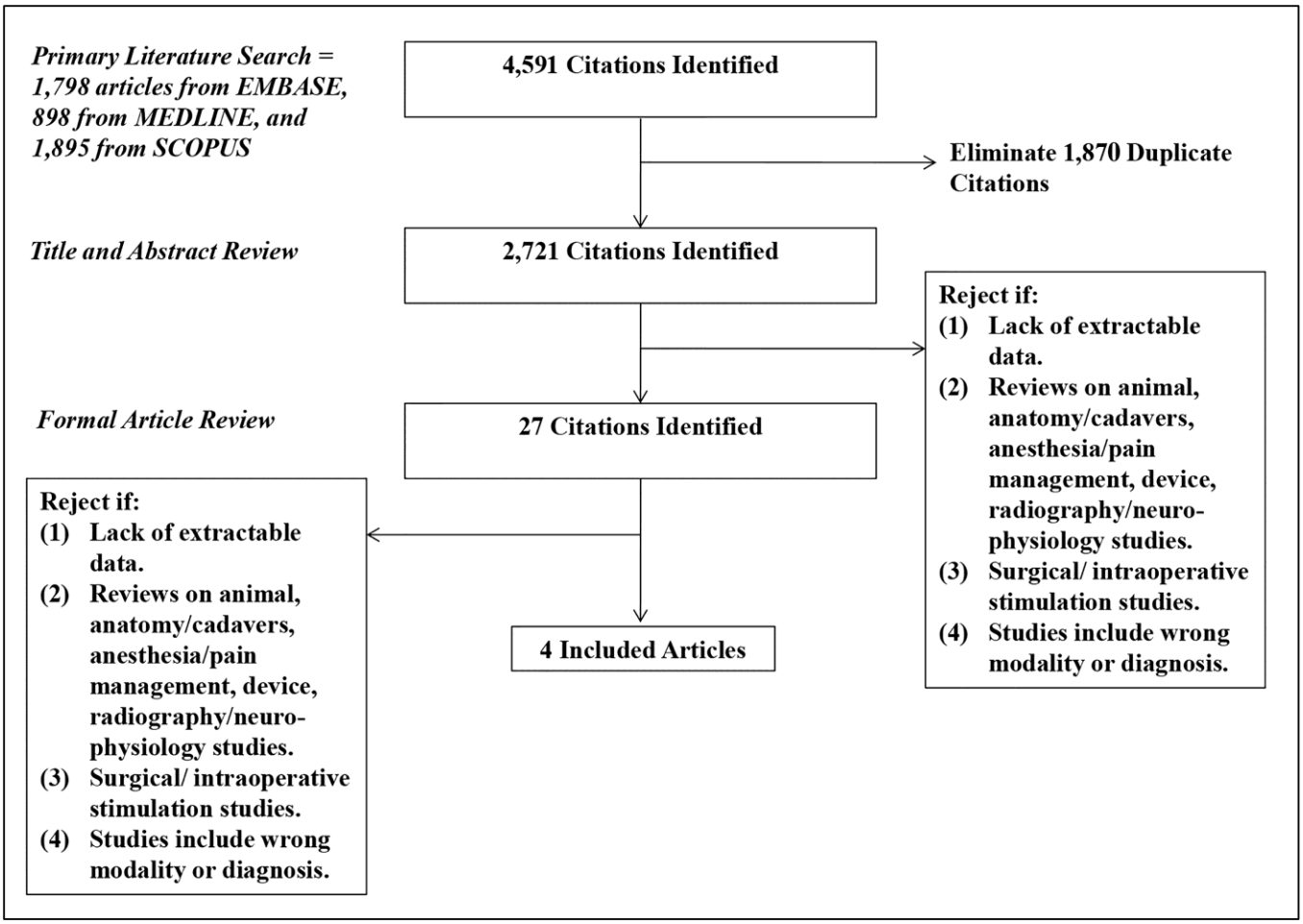

Figure 1. Flowchart highlighting articles retrieved and excluded from review.

Table 2

Comparison of Pre and Posttreatment Muscle Strength Scores (MRC) and Active Range of Motion (AROM)

Muscle Group	No. Patients	Pre-treatment MRC Scores	Posttreatment MRC Scores	Pre to Posttreatment Difference	No. Patients	Pretreatment AROM (degrees)*	Posttreatment AROM (degrees)*
Shoulder abduction	12	2	2	0	11	26 ± 28	63 ± 45
Shoulder flexion	2	1	4	3	2	150 ± 0	180 ± 0
Elbow flexion	11	2	2	0	9	10 ± 3.4	51 ± 48
Wrist extension	11	2	2	0	9	8 ± 3	46 ± 50

Note. AROM = active range of motion; MRC = Medical Research Council. *Values presented are mean ± SD.

Table 3

Comparison of Pre and Posttreatment Morphometric Parameters

Morphometric Parameter	No. Patients	Treatment Length	Pretreatment (% of unaffected arm)	Posttreatment (% of unaffected arm)
Arm length, cm	1	28 days	24 (98.7)	28.5 (100)
Arm circumference, cm	1	28 days	13.5 (98.5)	14.8 (100)
Arm circumference, cm*	8	6 weeks	15 ± 1	17 ± 1

Note. *Mean ± SD; unaffected arm circumference not reported.

Discussion

Therapists use NMES to apply electrical current to a partially or completely denervated muscle with the goal of promoting functional recovery. As early as 1868, Erb identified "degeneration syndrome," in which denervated muscle develops a sluggish response to electrical stimulation, thus requiring higher intensity and longer periods of stimulation for contraction (Cummings, 1985). In 1951, Osborne found that in six adult patients treated with electrical stimulation for severe peripheral nerve injury, atrophy was retarded during electrical stimulation; however, atrophy that occurred between stimulation and treatment was not reversed (Osborne, 1951). In treating NBPP, Eng et al. (1978) used electrical stimulation on a group of 11 pediatric patients with severe injury as part of a broader study of 135 NBPP patients; the authors noted minimal improvement (Eng et al., 1978).

There is a lack of consensus on the mechanism and effectiveness of NMES in humans. One potential mechanism includes inhibition of muscle atrophy during the period of reinnervation. A second possible mechanism is the acceleration of nerve regeneration itself (Al-Majed et al., 2000). However, studies are inconsistent on the effectiveness of NMES in preventing muscle atrophy. One study even suggests that NMES may inhibit nerve regeneration (Cummings, 1985). Part of the reason for the discrepancy in results may be the inappropriate use of high electrical intensity in certain studies. Inappropriately high intensity can cause muscle damage or fatigue and compromise the results (Cummings, 1985).

This review resulted in few eligible studies from the literature (see Figure 1). A major contributing factor may be the scarcity of human clinical studies involving NMES. Limitations of NMES suggested by neurophysiological studies and the controversy regarding its effectiveness from animal studies have possibly tempered impetus for further clinical evaluation in humans (Al-Majed et al., 2000; Tam & Gordon, 2003). One limitation of NMES suggested by neurophysiological studies is the manner in which motor units are activated during electrical stimulation. NMES results in the activation of motor units in a nonphysiological manner, resulting in increased muscle fatigue when compared to voluntary actions (Collins, 2007). In contrast to the sequence in voluntary contractions, larger axons are recruited first, which innervate the muscles that fatigue most rapidly (Collins, 2007). This limitation may contribute to the skepticism for NMES as an effective rehabilitation modality. With regard to animal studies, Al-Majed et al. (2000) found that electrical stimulation was effective in accelerating axonal regeneration in rats with femoral nerve lesions (Al-Majed et al., 2000). However, Tam and Gordon (2003) found that in rats with hind-limb injury, increased neuromuscular electrical stimulation reduced sprouting and motor unit enlargement. Given the controversy among animal studies, it is not surprising that discrepancies in human studies exist. However, for therapists using NMES, it is important to examine the effectiveness of NMES in the human population without discounting the results of animal research.

Three of the four included studies in this review were from outside of the United States and pertained to the pediatric population (see Table 1). In Nigeria and India, which have a World Bank Classification of lower-middle income (vs. the United States with a high-income classification), there is

likely increased incentive to explore the therapeutic potential of NMES, a relatively inexpensive intervention, along with other therapeutic interventions. There is, therefore, a greater likelihood of human clinical studies being conducted to evaluate this treatment modality in these countries. The focus on children is probably related to the plasticity of the developing nervous system. Pajevic, Basser, and Fields (2014) proposed that conduction velocity variation, mediated by myelin, was an important mechanism of activity-dependent plasticity (Pajevic et al., 2014). As myelination continues through adolescence to early adulthood, it was possibly hypothesized that children would be most likely to benefit from NMES.

NMES application can be categorized into three parameters: equipment settings, type of current, and placement of electrodes (Michlovitz, 2005). In terms of settings, direct interrupted current does not physiologically stimulate the muscle units and results in muscles that are not fatigue-resistant being recruited first (Cummings, 1985). Cummings (1985) proposed an "exponentially progressive current" of 50 to150 msec duration with a pause of 2 to 3 sec, 15 to 20 min daily (Cummings, 1985, p. 14). The benefit of a progressive current is that denervated muscle fibers can be preferentially selected by the gradually increasing current, preventing the overstimulation of innervated muscle fibers (Cummings, 1985). Most of the treatment modalities in the included studies were in this 15 to 20 min time frame per treatment, but it is not clear if the current was progressive or delivered at one level. It is possible, therefore, that fatigue-sensitive motor units were being recruited first, tempering the effect of the treatment even if treatment time was appropriate (Cummings, 1985). The application of NMES requires a careful consideration of target motor units to achieve optimal clinical effect. In terms of current, the two options include galvanic and faradic currents. Both currents are maximally effective in the 2 weeks following denervation (Cummings, 1985). Galvanic current stimulates denervated muscle, while faradic current stimulates innervated muscle. In one of the included studies, both currents were used to maximize the response and the patient did, in fact, make a strong recovery (Srilakshmi & Chaganti, 2013). As for electrode placement, Bergquist, Clair, and Collins (2011) argued for placement of the electrode over the nerve trunk rather than the muscle belly in order to promote a greater central contribution to motor unit recruitment (Bergquist, Clair, & Collins, 2011). This central contribution is associated with recruitment of low-threshold motor units first, which is more consistent with the natural physiological process and promotes more effective recovery of motor functions (Bergquist et al., 2011). None of the included studies referenced the exact placement of electrodes, but given the potential to harness a central contribution to motor unit recruitment, electrode placement over the nerve trunk may be an important component of a future standardized NMES protocol.

Aside from the application parameters of NMES, two other important considerations are timing of treatment and appropriateness of this modality for children with NBPP. The NMES starting time ranged from 3 weeks to 4.5 months in the included studies. Therapists should consider the extent and severity of NBPP when applying NMES on children. The more nerve roots (C5-T1) that are involved, the more extensive is NBPP; the Narakas scale (Narakas, 1987) is often used to represent the extent of NBPP. The severity of NBPP is classified via the Sunderland classification (I: neuropraxia, stretch; II: axonotmesis, disruption to axon and myelin; and III: neurotmesis, partial or complete disruption to the entire nerve fiber) (Seddon, 1942; Sunderland, 1951). If the axon is intact, the injured nerve can regenerate at a rate of 1 inch per month. Therefore, the first 3 to 6 months are critical for determining spontaneous recovery. If the patient shows progress in spontaneous recovery, therapists can discuss the option of NMES with the treatment team while accounting for nerve recovery status. Furthermore, therapists should undergo advanced training prior to using NMES. NMES is not suitable for individuals with cardiac conditions, pacemakers, hemorrhage risk, and thromboembolism risk. Care should be taken when using NMES on individuals who are pregnant or have epilepsy, decreased sensation, or a prosthetic joint. NMES should not be placed over carotid sinus, through the thorax, over diseased skin, or in the laryngeal area (Reed, 1997). The therapist should take precautions to avoid over-stimulating or fatiguing surrounding muscles.

The specific results regarding muscle strength suggests that there was no improvement in MRC scores for shoulder abduction, elbow flexion, or wrist extension (see Table 2). Shoulder flexion showed improved scores from 1 to 4, but this change is likely an artifact in magnitude, given that the reported initial AROM was much greater than would be expected to correspond to an MRC score of 1. As for the apparent lack of improvement in MRC scores overall, it should be noted that the study by Okafor, Akinbo, Sokunbi, Okanlawon, and Noronha (2008), which includes eight patients, likely skewed the overall pattern, as the three other individual cases all reported improvements of 1-2 MRC levels (Okafor, Akinbo, Okanlawon, & Noronha, 2008). The discrepancy between the Okafor et al. (2008) results and the other cases is possibly explained by three factors. First, the average age at intervention was 22 days, several days past the recommended upper limit of 2 weeks. Second, the settings were not reported and may have been at an inappropriate level. Third, the lesions in this series may have been more serious and therefore less likely to demonstrate improvement in response to NMES.

While MRC scores did not seem to demonstrate overall posttreatment improvement, AROM did reveal greater range in all reported joint parameters (shoulder abduction, shoulder flexion, elbow flexion, and wrist extension). Similar to the MRC scores, the marginal improvement reported in the Okafor et al. (2008) study attenuated the overall measurements. The three individual case reports included more striking AROM results (Adedeji & Oyelese, 2009; Berggren & Baker, 2015; Srilakshmi & Chaganti, 2013). One potential concern in assessing these improvements is whether NMES is being inappropriately credited for improvement that is simply the result of the action of intact muscle groups. However, as the results were reported by joint and not by muscle, this is less of a concern. AROM is an important parameter to include in this analysis, as it captures some of the nuance in improvement that may otherwise be missed by considering only MRC muscle strength values. Differences in AROM may not represent changes in level of function per se, but can reveal whether NMES is having a positive effect on which to build.

Regarding morphometric measurements, only one included study noted a minimal discrepancy in affected or unaffected ratios pretreatment, which resolved posttreatment (see Table 3) (Srilakshmi & Chaganti, 2013). Despite this resolution, it is difficult to draw any conclusions with regard to improvement in functionality based on these measurements.

This literature search did reveal other notable studies with results on the use of NMES. These studies were not included due to unreported pretreatment data. A case reported by Bliss and Mitchell (2011) involving isolated axillary nerve injury in an adolescent found that following NMES and physical therapy the patient demonstrated a posttreatment MRC of four with near-complete recovery of motor function (Bliss & Mitchell, 2011). This study demonstrates greater improvement than the overall changes observed in the included studies. The results may be due to the incomplete nature of these peripheral nerve injuries, which may be more amenable to NMES (Bliss & Mitchell, 2011). Another study by Limthongthang et al. (2014), which focused primarily on pain and safety outcomes, reported that pain scores (calculated on a visual analogue scale) fell from four pretreatment to three posttreatment and demonstrated that the NMES impulses did not damage the skin (Limthongthang et al., 2014).

Study Limitations

While it is appropriate for therapists to use measures such as muscle strength and AROM to gauge improvement in motor function, these assessments have their limitations. They only gauge what the patient can perform in the artificial setting of a clinic and do not reveal what a patient does or can do in a nonclinical setting, which would be a more meaningful description of functionality.

There are other limitations associated with this review. All four studies used different equipment and settings for NMES. There was also considerable variation in the adjunct modalities, including constraint-induced movement therapy in one case and ayurvedic treatment in another. The presence of accompanying treatment of any kind makes it challenging to assess the isolated effect of NMES. Further complicating this picture is the specific intervention of nerve transfer surgery that one patient

received, raising ambiguity about the individual effect of the surgery versus the subsequent NMES. The discrepancy between the reported MRC score for shoulder flexion and AROM in one of the cases also raises the issue of artifacts in reporting as a limitation. Furthermore, because of the patients' young ages, the included articles report only the *International Classification of Functioning, Disability, and Health* (ICF) (World Health Organization, 2001) body function and structure, whereas measures regarding functional outcomes are absent in the literature. The ICF body structure categories included in the articles are range of motion and MRC. However, MRC in infants can be difficult to rate based on their inability to follow directions to resist motion; we suggest future research relating ICF classification to MRC scores. Finally, the severity and extent of NBPP could also influence the effect of NMES treatment; however, the included articles did not report the exact etiology of the various lesions or their severity; thus, we cannot group and analyze the data in that clinical construct. The therapist should be aware of the severity and extent of NBPP when applying NMES treatment.

Conclusion

These results indicate that there is mixed evidence that NMES is associated with improvement in muscle strength. The studies are more consistent with improvement in AROM. However, with such a wide variation in treatment modalities, patient profiles, and adjunct treatment, the question of whether NMES is effective in treating peripheral nerve injury requires a clinical trial that could isolate the effect of NMES. As these studies did not report loss of motor function, and as there were reports of improvement in function, consideration of NMES in peripheral nerve therapy remains reasonable. It is important for therapists to understand that although the level of evidence is low, the use of the NMES modality for those diagnosed with peripheral nervous system conditions is not reported to prevent motor function recovery. Furthermore, the evidence supports the use of NMES in children with NBPP with a therapist's supervision. NMES should be used by properly trained therapists to ensure appropriate application of the stimulation while considering the extent and severity of the patient's condition and the proper settings of the device to prevent muscle fatigue or inadvertent stimulation of unintended muscles. This review further supports the need to expand the research to a higher level of evidence, perhaps a randomized controlled trial.

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Appendix

Medical Research Council (MRC) muscle function grading scale for shoulder, elbow, and wrist with equivalent angle degree

MRC Grade	Definition	Degree*
M0	No contractions	0
M1	Palpable but no visible contractions	0
M2	Movement when gravity has been excluded	1 - 79
M3	Movement against gravity	80 - 109
M4	Movement against resistance	110 - 160
M5	Normal muscle power	161 - max.

Note. *Degree values apply to shoulder and elbow range of motion only.