Pediatric Neurology 51 (2014) 360–364

Contents lists available at ScienceDirect

Pediatric Neurology

journal homepage: www.elsevier.com/locate/pnu

Original Article

Effects of Neuromuscular Electrical Stimulation on the Wrist and Finger Flexor Spasticity and Hand Functions in Cerebral Palsy

Mustafa Turgut Yıldızgören MD, Güldal Funda Nakipoğlu Yüzer MD, Timur Ekiz MD *, Neşe Özgirgin MD

Ankara Physical Medicine and Rehabilitation Training and Research Hospital, Ankara, Turkey

ABSTRACT

PURPOSE: To evaluate the effects of neuromuscular electrical stimulation on wrist range of motion, wrist and finger flexor spasticity, and hand functions in patients with unilateral cerebral palsy. **METHOD:** Twenty-four children with unilateral spastic cerebral palsy (14 boys and 10 girls) between the ages of 5 and 14 years were randomized into neuromuscular electrical stimulation and control groups. Conventional exercises were applied, and static volar wrist-hand orthosis was administered to all patients 5 days a week for 6 weeks. Additionally, 30-minute neuromuscular electrical stimulation sessions were applied to the wrist extensor muscles in the neuromuscular electrical stimulation group. Patients were evaluated by Zancolli Classification System, Manual Ability Classification System, and Abilhand-Kids Test. **RESULTS:** Compared with baseline, a significant increase was evident in active wrist extension angle at the fourth and sixth weeks in both groups (all $P < 0.001$), more prominent in the neuromuscular electrical stimulation group at the fourth and sixth weeks ($P = 0.015$ and $P = 0.006$, respectively). A decrease was observed in the spasticity values in the neuromuscular electrical stimulation group at the fourth and sixth weeks ($P = 0.002$ and $P = 0.001$, respectively) and in the control group only at the sixth week ($P = 0.008$). Abilhand-Kids values improved only in the neuromuscular electrical stimulation group ($P < 0.001$). **CONCLUSION:** Neuromuscular electrical stimulation application in addition to conventional treatments is effective in improving active wrist range of motion, spasticity, and hand functions in cerebral palsy.

Keywords: cerebral palsy, hand functions, functional electrical stimulation, spasticity

Pediatr Neurol 2014; 51: 360-364

Introduction

Cerebral palsy is the most common motor disability in childhood with an incidence of two to three per 1000 live births.[1] Several upper extremity problems affecting activities of daily living are observed in patients with cerebral palsy, and these problems require prolonged rehabilitation.[2] In this context, neuromuscular electrical stimulation (NMES) is an alternative method used for upper extremity disorders in patients with cerebral palsy.[3] It is imperative to apply the best available evidence-based interventions to children with cerebral palsy. Novak et al.[4] therefore classified the interventions in cerebral palsy into three main categories, whereby NMES has been reported to have lower level/inconclusive evidence.

Regarding NMES treatment for the upper extremity functions in patients with cerebral palsy, there are only a few studies in the pertinent literature. Only use of NMES has been reported in two case reports,[5,6] a pre-test and post-test design including nine children,[7] a baseline-intervention follow-up study including eight children,[8] and a baseline-intervention study including eight children.[9] Moreover, combined use of NMES treatment and splinting have been described in case reports or series,[10,11] a retrospective study comprising 19 children[12] and only one randomized trial consisting 24 children.[13] Xu et al.[3] documented the effects of constraint-induced movement therapy and NMES in 68 children with unilateral cerebral palsy. Overall, all these studies have described useful

Article History:
Received March 3, 2014; Accepted in final form May 12, 2014
* Communications should be addressed to: Dr. Ekiz; Ankara Fizik Tedavi ve Rehabilitasyon Eğitim ve Araştırma Hastanesi; Türkocağı Street; No:3 06230 Sıhhiye; Ankara, Turkey.
E-mail address: timurekiz@gmail.com

http://dx.doi.org/10.1016/j.pediatrneurol.2014.05.009

effects of NMES; however, they have yielded conflicting results for a standard NMES protocol with small sample sizes. Nevertheless, the combination of splinting, NMES treatment, and conventional exercises has not been studied yet. Therefore, the aim of this study was to investigate the effects of the combination of NMES, conventional rehabilitation program, and splinting on wrist and finger flexor spasticity, wrist extension, and hand functions of patients with spastic cerebral palsy.

Methods

Patients

Twenty-four unilateral cerebral palsy children (14 boys and 10 girls) with wrist and finger flexor spasticity who underwent inpatient rehabilitation were included in this study. Patients who had concomitant sight/hearing disorders, previous history of hand surgery or contracture in upper extremities, and dependent sitting balance were excluded. Informed consent was obtained from each patient's parents, and the study protocol was approved by the local ethics committee.

Study protocol and design

The patients were randomized into NMES and control groups. Conventional exercises and occupational therapy were applied, and static volar wrist-hand orthosis was administered to each patient 5 days a week for 6 weeks. Additionally, 30-minute NMES sessions were applied to wrist and finger extensor muscles of the patients only in the NMES group.

NMES protocol

A NMES device with a stimulator (SAMMS Mod. Professional; BEAC Bio-Medical, Italy) and two surface electrodes that have properties of adjustable on-off stimulation loop, stimulation density, and stimulation start and end were used. Electrical stimulation was applied with a tolerable and comfortable density (10-25 mA) and a pulse width of 300 μseconds, frequency of 30 Hz, an on-time of 12 seconds (includes a ramp-up of 1 second and a ramp-down of 1 second/an off-time of 5 seconds). To achieve maximum contraction of wrist and fingers, NMES was applied because the children were in a sitting position with their elbow, forearm, and hands in 90° of flexion, pronation, and neutral position, respectively. An inactive electrode was placed on the dorsal side of the wrist and an active electrode was placed on forearm's lateral side under the elbow. The same physiatrist (M.T.Y.) applied the NMES to all patients.

Neurophysiologic/conventional exercises

The conventional rehabilitation program consisted of neurophysiologic exercises using Bobath approach; active/passive range of motion (ROM) and stretching exercises were applied to all patients five times a week for 6 weeks (each session of 20-30 minutes).

Assessment/classification tests

All patients were evaluated before the beginning (baseline) and at the end of the third, fourth, and sixth weeks of the treatment. At each evaluation, active wrist extension, wrist and finger flexor spasticity, and hand functions were assessed. The affected side active wrist extension was measured using a goniometer after asking the patient to extend his/her wrist as much as he/she could do when the elbow was in 90° flexion and forearm was in pronation. The wrist and finger spasticity were rated by Zancolli Classification system in which hand grabbing and releasing functions were classified (Table 1).[14]

To evaluate the hand's functional activities and skills, five of six components of Jebsen Hand Function Test (JHFT; except for eating with a spoon simulation) were used. JHFT is a test measuring the time (seconds) spent on daily activities.[15] In our study, children were tested while sitting comfortably around a table. The same test was performed three times, and the mean duration was recorded. The maximal time allowed to complete each subtest was 120 seconds. The following five subtests were performed:

(1) Turning over five cards (12.7 × 7.5 cm)
(2) Picking up small common objects (two paper clips, two coins and crown caps)
(3) Stacking four checkers
(4) Picking up and displacing five large light cans
(5) Picking up and displacing five large heavy cans.

Moreover, patients were classified by Manual Ability Classification System,[16] and they were assessed by Abilhand-Kids test. Abilhand-Kids test is a valid and reliable test to evaluate hand skills in children with upper extremity involvement.[17] This test was completed by interviewing with the mothers of the patients at baseline and after sixth week of the treatment.

Statistical analysis

SPSS for Windows 11.5 program was used for statistical analysis. Shapiro-Wilk test was used to determine if the continuous variables were normally distributed. Descriptive statistics are indicated as mean ± standard deviation or median (minimum-maximum). Student *t* or Mann-Whitney *U* test (for continuous variables) and Pearson chi-square or Fisher exact test (for categorical variables) were used for the measurements between the groups, where appropriate. Mean or median values of the repetitive measurements within each group were analyzed using Bonferroni Correction, Multiple Comparison test, and Bonferroni Correction Wilcoxon Signed Rank test, respectively. A P value of < 0.05 was considered statistically significant.

Results

The demographic and clinical features of the patients are given in Table 2. Age, sex, involved side, Manual Ability Classification System levels and baseline values of Zancolli spasticity, JHFT periods, and Abilhand-Kids levels were similar between the groups (all $P > 0.05$). Both groups' changes in active wrist extension angles after the treatment are illustrated in Fig 1. Compared with baseline values, active wrist extension angle was increased in both groups at the fourth and sixth weeks (both $P < 0.001$), more prominent in the NMES group ($P = 0.015$ and $P = 0.006$, respectively).

Fig 2 displays the median Zancolli spasticity values of the patients. Compared with the baseline values, a decrease was observed in the NMES group at the fourth ($P = 0.002$) and sixth ($P = 0.001$) weeks and in the control group only at the sixth week ($P = 0.008$). The decrease levels according to the baseline values were significantly higher in the NMES group

TABLE 1.
Zancolli Classification

Type	Definition
Type I	Complete finger extension when the wrist is in neutral position or less than 20° flexion
Type IIA	Active wrist extension when the fingers are in more than 20° flexion
Type IIB	No active wrist extension when the fingers are flexed
Type III	No active finger extension when the wrist is in maximum flexion

than the control group at the fourth ($P = 0.001$) and sixth ($P = 0.016$) weeks. Although all patients indicated improvement in Zancolli stages in the NMES group, five of 12 patients stayed at the same Zancolli stage in the control group. Zancolli stages changed from IIB to IIA (n = 4), from IIB to I (n = 2), and from IIA to I (n = 6) with NMES treatment. In the control group, one patient improved from III to IIB and six patients improved from IIB to IIA, whereas four patients stayed as IIA and one patient as IIB.

Abilhand-Kids values of the groups are depicted in Fig 3. Although the Abilhand-Kids values increased in both groups, it reached significantly only in the NMES group ($P = 0.002$). There was improvement in JHFT times in both groups; however, this improvement was not statistically significant (all $P > 0.05$). Besides, there were no significant differences between the groups regarding time changes (all $P > 0.017$).

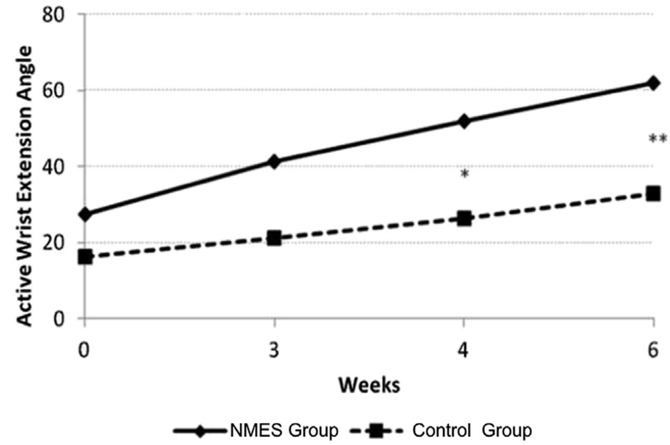

FIGURE 1.
Comparison of the wrist extension angle changes according to baseline values between the groups. When compared with baseline values, active wrist extension angle was increased in both groups at the fourth and sixth weeks (both $P < 0.001$). When compared between the groups, change levels were more prominent in the NMES group than the control group at the fourth (*$P = 0.015$) and sixth (**$P = 0.006$) weeks. NMES, neuromuscular electrical stimulation.

Discussion

In this study, we aimed to explore whether NMES treatment had an additional effect on rehabilitative treatment methods in children with cerebral palsy. Our results demonstrate that NMES treatment applied for at least 6 weeks in addition to conventional rehabilitation program and splinting had favorable effects on spasticity, wrist extension, and hand functions for the first time in the literature.

Novak et al.[4] have categorized the 64 discrete interventions in cerebral palsy into three lights (green, yellow, and red) according to "traffic light system." Effective interventions (24%) have been described as green and interventions that have uncertain effects (70%) have been described as yellow. Furthermore, interventions proven to be ineffective (6%) have been described as red. NMES treatment, neurophysiologic exercises, and splinting that we used in our study have been categorized under yellow lights.

According to our results, the increases in wrist extension after the 6 weeks were 34.6° (NMES group) and 16.7° (control group). These findings demonstrated that the NMES group had indicated more improvement than the control group. Improvement of the wrist extension values in the control group was similar to that of the results of the study conducted by Kamper et al.[9] Kamper et al.[9] reported that NMES treatment applied to seven patients with unilateral cerebral palsy (aged between 5 and 15 years) for 3 months indicated an improvement in wrist extension angle (14° at 6 weeks and 38° at 3 months). Increased active wrist extension after 6-week NMES treatment (about 10°) and decreased spasticity after 6-week NMES treatment applied to wrist extensors have also been reported.[8] Our findings and those of the aforementioned studies revealed that NMES treatment is more effective in increasing the ROM when it is combined with exercise and orthosis. Additionally, the effects of NMES were observed after 4 weeks of treatment.

NMES stimulates an agonist muscle contraction and inhibits the antagonist spastic muscle via the reflex arc. It also provides muscle re-education and strengthening without any significant side effects.[18,19] In this regard, NMES is a convenient application used for reducing spasticity, and it has been used in several studies.[8,9,13,19] In a study whereby the effects of a 5-week NMES treatment in 12 patients with hemiplegic cerebral palsy were evaluated, it has been revealed that Zancolli stages changed from IIA to I in seven patients and from IIB to I in five patients.[19] In another study (retrospective) in 19 patients with cerebral palsy, all patients' Zancolli stages improved one to three levels after the NMES treatment and a dynamic orthosis.[12] Ozer et al.[13] randomized 24 patients with hemiplegic cerebral palsy into only NMES treatment, only orthosis, or NMES plus orthosis treatment groups. After 6 months of follow-up, NMES plus orthosis combination was found to be more effective than the others. In our study, Zancolli stages changed from IIB to IIA (n = 4), from IIB to I (n = 2), and from IIA to I (n = 6) with NMES treatment. According to our results, in the

TABLE 2.
Demographic and Baseline Clinical Characteristics of the Patients

Variable	NMES Group (N = 12)	Control Group (N = 12)	P Value
Age (yr)	8.2 ± 2.2	7.4 ± 2.6	0.455
Sex (M/F)	7/5	7/5	1.000
Involved side (R/L)	6/6	5/7	0.682
Active wrist extension angle	27.5 ± 17.1	16.2 ± 14.3	0.095
Zancolli spasticity values	2 (1-3)	3 (2-4)	0.207
MACS values	3 (2-5)	3 (2-5)	0.974
Abilhand-Kids values	8.4 ± 2.5	7.7 ± 4.4	0.266

Abbreviations:
F = Female
L = Left
M = Male
MACS = Manual Ability Classification System
NMES = Neuromuscular electrical stimulation
R = Right
The values are given in mean ± SD, n, or median (minimum-maximum).

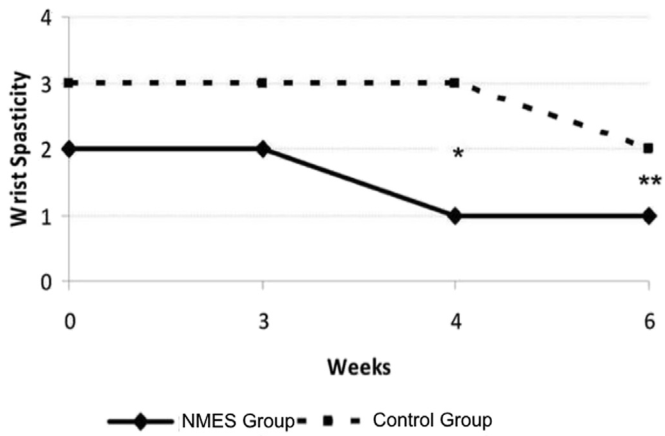

FIGURE 2.
Comparison of the Zancolli wrist spasticity changes according to baseline values between the groups. When compared with the baseline values, a decrease was observed in the NMES group at the fourth ($P = 0.002$) and sixth ($P = 0.001$) weeks and in the control group only at the sixth week ($P = 0.008$). The decrease levels according to the baseline values were significantly higher in the NMES group than the control group at the fourth ($^*P = 0.001$) and sixth ($^{**}P = 0.016$) weeks. NMES, neuromuscular electrical stimulation.

control group, one patient improved from III to IIB and six patients improved from IIB to IIA, whereas four patients stayed as IIA and one patient as IIB. Moreover, Zancolli values were found to be lower in the NMES group than in the control group on the fourth week and thereafter. Consequently, the improvement in Zancolli values was observed earlier and better when NMES treatment was combined with exercise and orthosis. Thus, we imply that NMES treatment in addition to conventional rehabilitation and static orthosis decreases the children's hand spasticity.

Wright et al.[15] applied NMES treatment to upper extremities and evaluated the efficiency by three subtests of JHFT (turning over cards, stacking checkers, and the six-object picking up test). The lowest improvement was observed in six-object picking up test. In our study, we used five subtests of JHFT. Eating with a spoon was excluded because it took too much time to concentrate children on simulating eating. At the end of the treatment, there was improvement in time spent on completing JHFT in both groups; yet this improvement was not statistically significant. We could attribute this to the wide range of impaired hand functions in cerebral palsy. The lack of writing task is one of the limitations in our study.

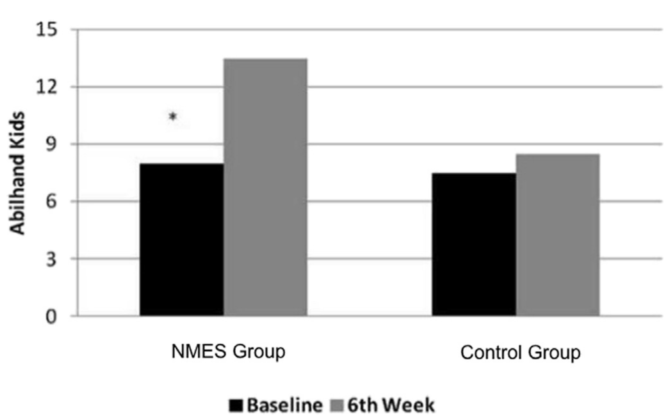

FIGURE 3.
Comparison of the Abilhand-Kids values according to baseline values within each group. Although the Abilhand-Kids values increased in both groups, it reached significance only in the NMES group ($^*P = 0.002$). There was improvement in JHFT times in both groups; however, this improvement was not statistically significant (all $P > 0.05$). Besides, there were no significant differences between the groups regarding time changes (all $P > 0.017$). JHFT, Jebsen Hand Function Test. NMES, neuromuscular electrical stimulation.

A recent study including 101 children with cerebral palsy concludes that the presence of hand deformities does not have a direct relationship with hand abilities.[20] Clinicians should evaluate hand abilities apart from hand deformities. The Abilhand-Kids test could be used to evaluate manual ability for children with upper limb impairments. In this regard, we used Abilhand-Kids to evaluate the children's hand abilities. Abilhand-Kids values increased after the treatment only in the NMES group. On the other hand, lack of bimanual performance assessment is a limitation of our study.

We have some limitations in our study. First, although our sample size is comparable to previous studies, the sample size could be larger. Second, children could be monitored longer than 6 weeks to better characterize the longer effects of NMES. Lack of only NMES treatment group and/or only orthosis group is a limitation of our study as well. The present study could be performed in a crossover design.

Conclusion

In light of our results, NMES treatment in addition to splinting and conventional exercises seems to be effective in improving active ROM, spasticity, and hand functions. Further studies should utilize a larger sample size including a crossover design and the effects of NMES along with other treatment modalities such as botulinum toxin.

Declaration of interest: The authors report no conflicts of interest.

References

1. Surveillance of Cerebral Palsy in Europe. Surveillance of cerebral palsy in Europe (SCPE): a collaboration of cerebral palsy surveys and registers. *Dev Med Child Neurol*. 2000;42:816-824.
2. Öhrvall AM, Krumlinde-Sundholm L, Eliasson AC. Exploration of the relationship between the Manual Ability Classification System and hand-function measures of capacity and performance. *Disabil Rehabil*. 2013;35:913-918.
3. Xu K, Wang L, Mai J, et al. Efficacy of constraint-induced movement therapy and electrical stimulation on hand function of children with hemiplegic cerebral palsy: a controlled clinical trial. *Disabil Rehabil*. 2012;34:337-346.
4. Novak I, McIntyre S, Morgan C, et al. A systematic review of interventions for children with cerebral palsy: state of the evidence. *Dev Med Child Neurol*. 2013;55:885-910.
5. Wright PA, Durham S, Ewins DJ, et al. Neuromuscular electrical stimulation for children with cerebral palsy: a review. *Arch Dis Child*. 2012;97:364-371.
6. Carmick J. Clinical use of neuromuscular electrical stimulation for children with cerebral palsy, Part 2: upper extremity. *Phys Ther*. 1993;73:514-522. discussion 523–527.
7. Vaz DV, Mancini MC, da Fonseca ST, et al. Effects of strength training aided by electrical stimulation on wrist muscle characteristics and

hand function of children with hemiplegic cerebral palsy. *Phys Occup Ther Pediatr*. 2008;28:309-325.
8. Wright PA, Granat HM. Therapeutic effects of functional electrical stimulation of the upper limb of eight children with cerebral palsy. *Dev Med Child Neurol*. 2000;42:724-727.
9. Kamper DG, Yasukawa AM, Barrett KM, et al. Effects of neuromuscular electrical stimulation treatment of cerebral palsy on potential impairment mechanisms: a pilot study. *Pediatr Phys Ther*. 2006;18:31-38.
10. Carmick J. Use of neuromuscular electrical stimulation and [corrected] dorsal wrist splint to improve the hand function of a child with spastic hemiparesis. *Phys Ther*. 1997;77:661-671.
11. Postans N, Wright P, Bromwich W, et al. The combined effect of Dynamic splinting and Neuromuscular electrical stimulation in reducing wrist and elbow contractures in six children with Cerebral palsy. *Prosthet Orthot Int*. 2010;34:10-19.
12. Scheker LR, Chester SP, Ramirez S. Neuromuscular electrical stimulation and dynamic bracing as a treatment for upper extremity spasticity in children with cerebral palsy. *J Hand Sur Br*. 1999;24:226-232.
13. Ozer K, Chester SP, Scheker LR. Neuromuscular electrical stimulation and dynamic bracing for the management of upper-extremity spasticity in children with cerebral palsy. *Dev Med Child Neurol*. 2006;48:559-563.
14. Zancolli EA, Goldner LJ, Swanson AB. Surgery of the spastic hand in cerebral palsy: report of the committee on spastic hand evaluation. *J Jand Surg*. 1983;8(5 PT 2):766-772.
15. Jebsen RH, Taylor N, Trieschmann RB, et al. An objective and standardized test of hand function. *Arch Phys Med Rehabil*. 1969;50:311-319.
16. Ohrvall AM, Eliasson AC. Parents' and therapists' perceptions of the content of the Manual Ability Classification System, MACS. *Scand J Occup Ther*. 2009;17:1-9.
17. Arnould C, Penta E, Renders A, et al. ABILHAND-Kids: a measure of manual ability in children with cerebral palsy. *Neurology*. 2004;63:1045-1052.
18. Scheker LR, Ozer K. Electrical stimulation in the management of spastic deformity. *Hand Clin*. 2003;19:601-606.
19. Mäenpää H, Jaakkola R, Sandström M, et al. Electrostimulation at sensory level improves function of the upper extremities in children with cerebral palsy: a pilot study. *Dev Med Child Neurol*. 2004;46:84-90.
20. Arnould C, Penta E, Thonnard JL. Hand impairments and their relationship with manual ability in children with cerebral palsy. *J Rehabil Med*. 2007;39:708-714.

"In my experience" is a phrase that usually introduces a statement of rank prejudice or bias. The information that follows cannot be checked, nor has it been subjected to any analysis other than some vague tally in the speaker's memory.

Michael Crichton, 1971