Neuromuscular Electrical Stimulation Versus Progressive Resistive Exercises for Improving Wrist Extension in Cerebral Palsied Children

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ABSTRACT

***Purpose:** This study was designed to compare between the effects of neuromuscular electrical stimulation (NMES) and progressive resistive exercises (PRE) for improving wrist extension in children with cerebral palsy (CP). **Methods**: Thirty six children with spastic CP (Diplegics, n=20; Hemiplegics, n=10; Quadriplegics, n=6) with (mean age 8 years ± 1 years and 3 months, range 6 to 10 years) participated in a six-week treatment program. Children were classified into two equal homogenous groups, one received NMES for the wrist extensors and the other received a program of PRE for wrist extensors. All children were evaluated before and after intervention for active and passive wrist extension range of motion, muscle tone, and isometric muscle force of wrist extensors. **Results:** Significant differences were found between NMES and PRE groups after treatment in respect to improvement in active and passive ROM as well as in isometric wrist extension force and this improvement was in favor of the PRE group (P = 0.000, p = 0.007, P = 0.000 respectively). A significant decrease in muscle tone was detected after the NMES protocol while no significant change could be detected after the PRE protocol (P = 0.006, P = 0.77 respectively). **Conclusion**: PRE was effective in increasing active and passive wrist extension range as well as the isometric force of wrist extensors to an extent greater than NMES. On the other hand, NMES was effective in tone reduction of spastic muscles while PRE had no effect on muscle tone.*
***Key words**: Cerebral palsy; electrical stimulation; strength; resistive exercises; isometric force.*

INTRODUCTION

Hand is typically affected in children with cerebral palsy. The stereotypical posture of wrist flexion and ulnar deviation, coupled with finger and thumb flexion into the palm, hinders hand grasp and release. Impairments in upper extremities in CP may include muscle tone abnormality, imbalance between agonists and antagonists, spasticity, alignment problems, decreased strength, and impaired motor control[1,2]. Combination of these primary impairments can and have been targeted for various rehabilitation strategies, including surgery[3], casting[4], physiotherapy, and medication[5, 6].

Neuromuscular Electrical Stimulation Issues in Cerebral Palsy

Neuromuscular electrical stimulation (NMES) is transcutaneous application of electrical current to innervated, superficial muscle to stimulate muscle fibers, augment muscle contractions, increase range of motion (ROM), and enhance sensory awareness[7,8]. The broad term NMES involves the external control of innervated yet paretic or paralytic muscles by electrical stimulation (ES) of the corresponding intact peripheral nerves[8]. In athletes, NMES has been shown to increase muscular strength[9] and therefore it could be speculated that stimulation of this kind as an adjunct to physical therapy in children with CP would enhance the options for new active movements[10,11].

Electrical stimulation is thought to improve strength[12], reduce spasticity of the antagonist muscle[13], reduce spasticity of the stimulated muscle[14], reduce cocontraction[15], and/or create soft-tissue changes permitting increased range of motion[16]. Several case studies have reported improvement in hand function or use following a regimen of NMES treatment[7,17,18,19]. Two larger studies also described the potential efficacy of NMES in improving function[15, 16]. Improvement in active wrist movement and performance of timed object manipulation tasks may be maintained after the stimulation protocol is ended[16,18].

Strength Issues in Cerebral Palsy

Classifying patients with CP as hemiplegic, diplegic, and quadriplegic describes the distribution pattern of spasticity but, more relevant to this study, directly implicates weakness as one of the hallmark clinical characteristics of this population[20]. One of the accepted definitions of strengthening is an increase in the force generation capability of muscle tissue due to physiologic differences[21]. In the traditional treatment of children with CP, strengthening programs have been avoided for the reasons identified by Damiano et al.,[22] (1) the possibility of increasing spasticity and thereby exacerbating further muscle contractures and joint stiffness, (2) adolescents with CP lack the isolated muscle control needed to increase strength in targeted muscles, and (3) weakness is not considered to be the primary limiting factor of motor function.

Although questions still exist regarding the effectiveness of strength training, a number of studies have demonstrated that strength training can be implemented without increasing spasticity. Research by Bohannon[23] supports the concept that patients with brain lesions, whose muscles function differently than expected under normal circumstances, can still achieve strengthening. Similarly, Damiano et al.,[22] suggested doing resistance exercise in a more functional position as suggested by the principle of specificity of training.

A number of researchers provided evidence that supports the benefits of strengthening programs in this patient population. Damiano et al.,[22] focused on increasing quadriceps muscle strength in children with CP and the majority of his children attained normal strength values. He showed that strengthening the knee extensors decreased the amount of knee flexion during stance and increased stride length during gait. These findings were thought to be due to the improved balance of the agonist-antagonist relationship at the knee[21]. Horvat[24] also demonstrated the effectiveness of strengthening a patient with spastic CP through a progressive resistance training program using free weights and weight machines. Strength was assessed on a Cybex II Isokinetic System. Strength, muscular endurance, and range of motion gains were noted on both sides of the body indicating a general improvement, with the greatest improvements observed in the involved lower extremity[24].

The aim of the present study was to compare between the effects of neuromuscular electrical stimulation (NMES) and progressive resistive exercises (PRE) on problematic wrist extension in children with spastic cerebral palsy (CP).

MATERIAL AND METHODS

Participants

Thirty six CP children (22 males, 14 females), mean age 8 y ± 1 y and 3 months, range 6 to 10 years, with spastic diplegia, n = 20; hemiplgia, n = 10; quadriplegia, n = 6, participated in the study. Inclusion criteria included spastic paresis (The degree of spasticity of all children ranged from grade 1 to grade 3 measured at the wrist joint according to the modified Ashworth scale[25]), impaired voluntary wrist extension movement (defined as being less than the passive range or absence of selective active wrist extension), passive range of wrist extension > 25 degrees with the fingers curled, sufficient passive supination to bring the forearm to neutral, and sufficient cognitive skills to follow verbal directions and to cooperate during physical therapy sessions. Exclusion criteria included children who had a history of Botox injections for the past six months, dorsal rhizotomy, or use of a baclofen pump due to the lack of knowledge regarding their effects on the capacity for strength training. Informed consent was obtained from all children prior to testing. Children were classified into two equal homogenous groups. Each group composed of 10 dipelgics, 5 hemiplegics, and 3 quadripelgics. One received neuromuscular electrical stimulation (NMES) for the wrist extensors and the other received a program of progressive resistive exercises (PRE) for wrist extensors. Children were assigned randomly to NMES or PRE groups by selecting a group from a hat.

Treatment

The basic therapy for these children was physical therapy based on neurodevelopmental training techniques. This was not modified during the study period of six weeks. Duration and frequency of physical therapy had been set to one hour, three times weekly (every other day).

Stimulation Protocol

An ENS 931 (Enrauf Nonius, Stimulator, Netherlands) EMPI unit was used as the neuromuscular electrical stimulator. This equipment produces symmetrical biphasic waveforms. The battery-powered stimulator has two channels that allow two different muscle groups to be stimulated at the same time. The small size of the portable device allows the child to move freely. Self-adhering electrodes (EMPI, 5×5 cm) were placed on clean skin. The so-called active electrode was placed on the common extensor origin targeting both extensor carpi ulnaris and radialis and the other electrode was placed distally on the dorsal surface of the lower third of the forearm. The distance between the two electrodes equals at least the size of one of them.

During the first three weeks stimulation parameters were set according to the previously defined protocol[26]. Namely, pulse duration was fixed at 280 μs, stimulation frequency was set to 35 Hz, and a pattern of five seconds extensors on/five seconds rest. Ramp up time was set to 0.5 seconds and ramp down time to zero. The amplitudes were set to maximize wrist movement while still being comfortable for the child. NMES sessions consisted of 15-minute periods conducted three days per week. children were instructed to work in synchrony with the stimulation to produce wrist extension. For the second three-week period, the stimulation pattern consisted of 10 seconds on/10 seconds off. When a child was able to achieve full wrist extension against gravity with the aid of the stimulation, the child and his or her guardians were instructed to increase resistance to wrist extension during the stimulation by having the child carries objects or weights. NMES session length was extended to 20 minutes, but the stimulation parameters and weekly frequency were kept the same as during the first three weeks.

Strengthening Protocol

A strength-training program was performed three times per week for the six weeks period. The training program was focused on wrist extensors using free weights and weight machines. In instances when the available equipment was inadequate or weight increments were too large, exercises using cuff weights and Theraband, were substituted. Verbal feedback and visual demonstration were given as needed. The exercise load (originally established as 80% of each child's one repetition maximum) and repetitions (originally eight to 10) were progressed as follows: (1) During the first two weeks we increased repetitions of the original load, (2) During the middle two weeks we increased load and decreased repetitions to the initial number of repetitions, and then (3) During the last two weeks we increased repetitions at the increased load. Children were asked to perform several stretches before and after their strengthening workout. Children spent an average of 10 minutes to 15 minutes to complete the PRE session. Children were asked to record any muscle soreness or other complaints that occurred while exercising.

Evaluation

All children were assessed before and after the six-week treatment period. The same evaluation protocol was conducted for all children and carried out by trained physical therapists that practiced extensively using the HHD on children with CP before collecting data. Based on the average of both sides, measurements were taken for the diplegic and quadriplegic children, while measurements were taken for the affected side in hemiplegic cases.

Muscle tone

Modified Ashworth[25] scale was used to measure the average degree of resistance exhibited to passive movement. This scale was applied to the affected wrist flexors. The modified Ashworth scale (MAS) for spasticity as published is scored 0–4, with a 1+ grade, but for data analysis the scores were adjusted to give a 0–5 score range (1+ became 2, 2 became 3, and so on).

Range of motion

While the child was in sitting position and the shoulder adducted and flexed (90°), elbow extended, forearm pronated, and fingers curled peak active and passive wrist extension range of motion against gravity were measured using a standard goniometer. Keeping the child in the same position but with the forearm in neutral regarding rotation (i.e without gravity) active range measurement was repeated.

Isometric muscle force

Isometric force measurements were recorded with a Chatillon CSD400 HHD (John Chatillon & Sons, Inc., Greensboro, NC). The HHD was calibrated with weights before beginning data collection and was found to be accurate within ±0.89 Newton (N), which is the same accuracy reported in the Chatillon HHD manual. Each child was seated on a chair with a device for upper limb stabilization attached. The padded end piece of the HHD was positioned against the dorsum of the hand and procedures were conducted. Isometric strength test of wrist extensors were performed with pronated forearm (against gravity), curled fingers, and neutral wrist regarding flexion/extension.

Children were given two to three practice trials for each test until the investigator was confident that they understood the task. They were instructed to gradually "push as hard as possible" over a period of approximately five seconds until the examiner told them to relax. After practicing, each child performed three trials and the peak force values from the dynamometer were recorded. For each trial, a “make” test was performed, in which the children were asked to push their limb harder against the dynamometer (held rigidly by the examiner perpendicular to the child’s limb segment) until they reached their maximum force. The “make” test has been shown to be more reliable than a “break” test, in which the examiner tries to overcome the force exerted by the Child. The HHD was adjusted to begin recording two seconds after the Child achieved a 4.45-N threshold and then continued to record data for three seconds. The dynamometer calculated the peak force from that three-second reading. The two-second delay in recording was programmed into the dynamometer to allow the child to build up peak force slowly to avoid possible injury due to a sudden muscle contraction.

Statistical Analysis

A descriptive statistics was done for all sets of measurements, before and after treatment in both groups (NMES and PRE). Paired t-test was conducted to compare between the results collected before and after treatment for each treatment group. To determine whether significant differences existed between the NMES and PRE groups, independent t-test was conducted to compare between the results in both groups before and after the treatment course. P-value <0.05 will be considered significant.

RESULTS

Our results revealed that there were no significant differences between NMES and PRE groups at entry in respect to Ashworth score, active wrist extension range against and without gravity, passive wrist extension range and isometric force of wrist extensors (P = 0.87, P = 0.42, P = 0.12, P = 0.67, P = 0.38 respectively) (Table I).

Table (1): Baseline demographic and clinical data.

Variables		(NMES) group				(PRE) group				cP
		Pre	Post	Improv.	bP	Pre	Post	Improv.	bP	
Ashworth scale	Mean (SD)	2.9 ±1.1	2.3±0.8	-0.67 ±0.9	0.006*	3.0±1.0	3.1 ±0.9	0.1 ±0.8	0.772	0.007*
Active wrist extension range (Against gravity)	Mean (SD)	21.7±10 .4	27.2±11 .8	5.5 ±5.4	0.001*	25.0±13 .7	45.2 ±11.8	20.2 ±7.9	0.000*	0.000*
Active wrist extension range (Without gravity)	Mean (SD)	27.0±12 .3	33.0±13 .3	6.0 ±4.1	0.000*	35.0±17 .7	50.0 ±11.8	15.0 ±9.1	0.000*	0.000*
Passive wrist extension range	Mean (SD)	52.2±15 .5	53.7±14 .5	1.4 ±2.9	0.046*	54.4±15 .7	61.3 ±10.0	6.9 ±7.5	0.001*	0.073
Isometric force (aN)	Mean (SD)	21.4±5. 6	27.2±6. 8	5.8 ±4.1	0.000*	23.3 ±7.1	37.2 ±7.4	13.9 ±7.4	0.000*	0.000*

[a] N (Newton)
[b] Difference tested with paired t-test between the pre and post measurements for each group.
[c] Difference tested with independent t-test between the two groups for the post measurements.
[*] Values significant at P<0.05.
Improv. (Improvement).

Range of motion

The program of PRE was effective in increasing active wrist extension range of motion (against gravity and without gravity) by an average of (20.2±8.0 and 15.0±9.1 degrees respectively) compared to (5.5±5.4 and 6.0±4.1degrees respectively) for the NMES group and this difference was statistically significant (P = 0.000, P = 0.000 respectively). Also, passive wrist extension range of motion increased after PRE by an average of (6.9±7.51degrees) compared to (1.4±2.91degrees) for the NMES, but this difference between the two groups was not significant (P value equal 0.07) (Table I, Figure 1).

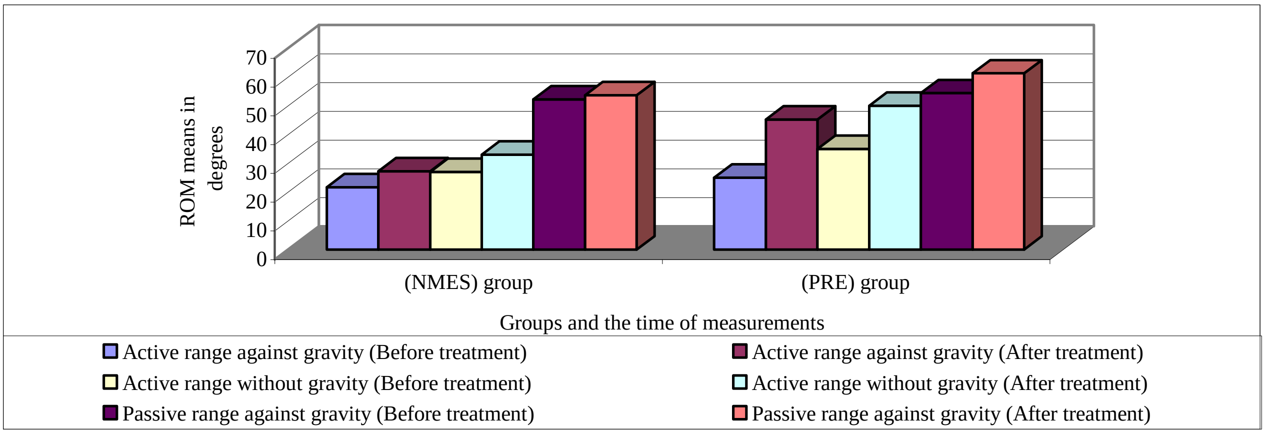

Fig. (1): Comparison between measurements of active and passive wrist extension range before and after treatment in both groups.

Isometric muscle force

The statistical tests also indicated that the PRE group had a significantly greater increase in isometric wrist extension force than the NMES group (13.9±7.4 and 5.8±4.1 respectively) with P value equal 0.000 (Table I, Figure 2).

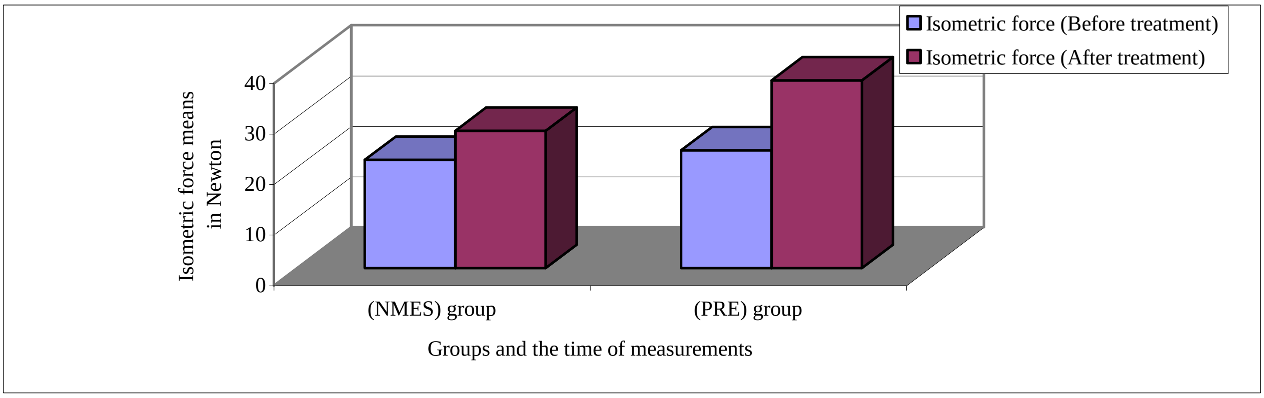

Fig. (2): Comparison between measurements of isometric force of wrist extensors before and after treatment in both groups.

Muscle tone

On the other hand, results of the NMES group revealed significant decrease of Ashworth score by an average of (0.67±0.9) with p value equal 0.006, while no significant change could be detected in Ashworth score in PRE group (0.1±0.8) with P value equal 0.77 (Table I, Figure 3).

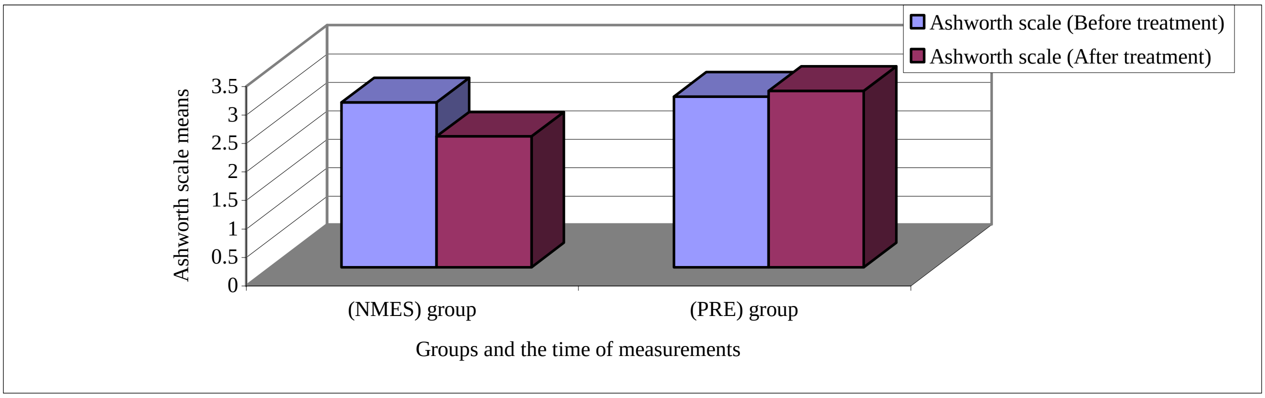

Fig. (3): Comparison between measurements of Ashworth scale before and after treatment in both groups.

DISCUSSION

Elder et al.,[27] attributed weakness in children with CP to incomplete activation of the agonist muscle and excessive coactivation of the antagonist. The lower level of physical activity observed in this population is one potential contributor to weakness[28]. Other possible factors include decreased central input to the muscle due to a pyramidal tract insult[29], changes in the elastic properties of the muscles themselves[30], aberrations in the reciprocal inhibition pathways in agonist–antagonist muscle pairs[31], and heightened stretch responses or spasticity[32]. We agree with Damiano et al.,[33] who stated that some of the above factors may be secondary, rather than primary impairments, and may be preventable, at least in part, if sufficiently intense intervention is provided before these secondary factors ensue. It is important to mention that isometric dynamometry testing have been shown to be reliable in spastic disorders like cerebral palsy (even in children as young as 4 to 5 years of age)[34].

In accordance with several studies, our children did demonstrate improvement in active and passive wrist extension range of motion following the NMES program[15, 16] and the PRE program[20,22,24]. Improvement in active and passive wrist extension range was statistically higher in the PRE group than the NMES. Increase in active wrist extension occurred despite a lack of correspondence reduction in spasticity in contrast to what has been reported for adult hemiparetic children. In fact, the PRE treatment had no significant effect on spasticity in general. Thus, it is possible for improvements in motor control to occur without reduction in spasticity[13]. Repeated contraction and use of the wrist extensor muscles against progressive resistance may have caused the active muscle fibers to hypertrophy, thereby increasing muscle strength. Alternatively, neural adaptations may have led to improvement by reducing flexor coactivation and/or increasing excitation of the wrist extensor muscles[27]. Also, Damiano et al.,[22] proved that isokinetic and isotonic training programs in this

population have been shown to increase muscle force and improve motor performance.
On the other hand and in agreement with our findings, electrical stimulation repetitively excites specific peripheral nerves and sensory organs, generates afferent feedback (through movement of the wrist in the intended direction), and reinforces the activity and increase muscle strength[12]. Furthermore, ES may reduce spasticity of the antagonist muscle[13], reduce spasticity of the stimulated muscle[14], reduce cocontraction[15], and/or create soft-tissue changes permitting increased range of motion[16].

Generalizability of these results, however, is limited because children served as their own controls. Thus, the observed improvement may not be entirely attributable to the NMES or PRE. It is doubtful, however, that the improvement occurred spontaneously. All children were at least six years in age and had received therapy in the past, so the children presented with a fairly stable level of hand function prior to this study. Indeed, another study reported only limited changes in hand function after four years of age in children with hemiplegic CP[36].

In conclusion, the results of this study do suggest that the prescribed PRE protocol holds promise in improving active and passive wrist extension range with an increase in isometric wrist extension force, this to an extent greater than improvement with NMES protocol. This improvement was not associated with a reduction in spasticity.

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الملخص العربي

التنبيه الكهربائي العصبي العضلي مقابل تمرينات المقاومة التقدمية لتحسين فرد الرسغ في الأطفال المصابين بالشلل الدماغي

تهدف هذه الدراسة إلى المقارنة بين تأثيرات التنبيه الكهربي و التمرينات التقدمية وذلك في تحسين مشكلة فرد الرسغ عند الأطفال المصابين بالشلل الدماغي. أجريت هذه الدراسة على 36 طفل من مرضى الشلل الدماغي التصلبي تتراوح أعمارهم ما بين 6 إلى 10 سنوات. قسمت عينة الدراسة عشوائيا إلى مجموعتين متساويين ومتجانستين تم تطبيق برنامج تنبيه كهربائي لأطفال المجموعة الأولى على عضلات فرد الرسغ لمدة تتراوح بين 15-20 دقيقة ثلاث مرات أسبوعيا، في حين تم تطبيق برنامج التمرينات التقدمية على أطفال المجموعة الثانية لمدة تتراوح بين 15-20 دقيقة ثلاث مرات أسبوعيا وكانت مدة العلاج الكلية في كلا من المجموعتين 6 أسابيع، علما بأنه لم يتوقف تطبيق نفس برنامج العلاج الطبيعي العادي لأطفال المجموعتين طول مدة الدراسة . تم قياس المدى الحركي الإرادي والقصرى لفرد مفصل الرسغ والنغمة العضلية وقوة عضلات فرد الرسغ وذلك قبل وبعد العلاج. أشارت النتائج لوجود فروق ذات دلالة إحصائية بين المجموعتين وذلك في صالح مجموعة التمرينات التقدمية فيما يتعلق بالتحسن في المدى الحركي الإرادي و القصرى والقوة العضلية. أما فيما يتعلق بالنغمة العضلية فقد كان التحسن في صالح مجموعة التنبيه الكهربائي. علما بأنه لم يتغير مقياس النغمة العضلية بعد تطبيق برنامج التمرينات التقدمية عن قيمته قبل تطبيق هذا البرنامج. وعليه يمكن أن نوصي باستخدام التمرينات التقدمية في علاج مشكلة فرد مفصل الرسغ في أطفال الشلل الدماغي وكذلك استخدام التنبية الكهربائى لتقليل النغمة العضلية وذلك لما حققته من نتائج فعالة ذات دلالة إحصائية .