This report, part 2 of a two-part case report on the clinical use of neuromuscular electrical stimulation (NMES) for children with cerebral palsy, documents the functional changes that occurred with the application of NMES to the upper extremity of two children, 1.6 and 6.7 years of age, with hemiplegia due to cerebral palsy. The NMES was used as an adjunct to a dynamic-systems, task-oriented physical therapy program. The youngest child showed immediate improvement in the ability to crawl and use both hands together. The older child demonstrated increased sensory awareness and use of the nonfunctional hand. Preliminary findings suggest that NMES may be a useful physical therapy tool for enhancing muscle strength, increasing sensory awareness, and assisting motor learning and coordination.

**Key Words:** Cerebral palsy, Motor control, Neuromuscular electrical stimulation, Pediatrics, Upper extremity.

This report, part 2 of a two-part case report on the clinical use of neuromuscular electrical stimulation (NMES) for children with cerebral palsy, documents the use of NMES for improving the motor control and sensory awareness of the upper extremity of two children with hemiplegic cerebral palsy from birth. The NMES was given as an adjunct to a dynamic-systems or contemporary motor-learning physical therapy program. The principles of motor learning that were emphasized included playing in a task-specific activity in a position in which the stimulated muscle would normally function and allowing the child freedom to make mistakes and learn from them. The children in this report are the same children discussed in cases 1 and 2 in part 1 of the two-part case report.

**Neuromuscular Electrical Stimulation Equipment Used**

The Respond II unit* was used. This unit has two channels that allowed two different muscles to be stimulated at the same time or at alternating times. Electrical stimulation was always kept within the child's tolerance.

The portability of the unit allowed the child to move freely. A remote-control switch was used to stimulate the muscle as needed.

Reuseable, self-adhering, pregelled, carbonized-rubber electrodes* were used. The active electrode was placed on the motor point, and the inactive electrode was placed on the same muscle or muscle group a short distance away from the active electrode. The active electrode was cut to size, never smaller than a nickel, so that only the desired muscle would be stimulated and thus eliminate or decrease overflow. The suggestions of Baker and Parker1 and Delitto and Robinson2 for electrode placements were often used.

The pulse rate was often initially set to about 5 to 7 pulses per second (pps), which gave a tapping sensation...
and sensory input but not a fused contraction. When this sensation was tolerated by the child, the setting was increased to between 30 and 35 pps to give a fused muscle contraction. The amplitude was slowly increased until a contraction could be felt and kept within the child's tolerance.

The output-limit control was set for 50% of the stimulator's maximum amplitude. The amplitude was increased very slowly, to the child's tolerance, and only when the current was on. As the child became familiar with the simulation, his tolerance increased and the amplitude could be increased to obtain a stronger muscle contraction. It was not necessary to have a maximal contraction to increase sensory awareness or strength of the weak muscle. With a low pulse rate, a higher amplitude is tolerated. Thus, the muscle contraction can be more easily seen so that the physical therapist can determine whether the correct muscle is being stimulated before changing the rate to obtain a sustained muscle contraction at a less visible amplitude.

The ramp, or rise time, was initially set at the lowest setting (8 seconds) for the most comfort. When the child was accustomed to NMES, the ramp was set for approximately 2 seconds. When a quicker response was needed, such as during gait, the fastest rise time (0.5 second) was used. On-off times initially were set for 10 seconds on and 25 seconds off. Once the child was comfortable with electrical stimulation and not showing signs of fatigue, the cycle was set at 15 seconds on and 15 seconds off for a total of 15 to 20 minutes. When the remote-control switch was used, the on time was determined by activation of the switch, which was facilitated according to the child's functional needs. For example, when the child was picking up an object to put into a container, the electrodes on the wrist extensors were facilitated with the remote-control switch the entire time he was doing the movement. This could be longer or shorter than 15 seconds. The finger extensors were then stimulated at the time of release until the release was accomplished. All electrodes were then silent when the child returned his arm to pick up another item.

The electrodes could also be used to assist with opening of the hand to grasp an item. When the child was first experiencing wrist extension with NMES, the alternating mode was used as he played with toys on a table. Wrist extension is used for both grasp and release, so the periodic timing of the unit cycling on and off for 15 seconds on the wrist extensors as he played would not have interfered with the acquisition of wrist extension skill. When he was comfortable with NMES and could tolerate a quicker rise time, the remote-control switch was used to stimulate the muscle when he began to reach or to release.

The child was given time to experience and accept the sensation. Letting the child in case 2 turn the unit on and off with the remote-control switch gave him appropriate control initially. He was almost 7 years of age and curious about mechanical items. He was also interested in what was going to happen to him, and he needed to have some control over the situation in order to more easily accept the intrusion. When the child was allowed to use the remote-control switch, he could determine how long or how short the stimulation would be. He was learning what would happen if he left it on. It took only a short time for him to understand the mechanics and to be satisfied that all would be com-

Figure 1. Child in case 1 at 10 months of age, before neuromuscular electrical stimulation, shown as he was attempting to creep. He continued with this creeping style, with no weight bearing on the left upper extremity unless given assistance, until age 15 months when he could walk. After he learned to walk, he was not interested in creeping.
The children in cases 1 and 2 were first introduced to a hand-held vibrator, which was called a "tickler." The NMES was described as being like the "tickler," and the children were told they would feel a tapping sensation. The electrode was then placed on the cleaned body part. The amplitude was initially increased very slowly until the child indicated that he felt the stimulation or until a trace contraction was felt or seen. As the child became accustomed to the stimulus, a higher amplitude was used to obtain a stronger contraction.

**Case 1**

The child in case 1 was a 19-month-old boy who was diagnosed with left hemiplegia secondary to cerebral palsy following a computerized tomography (CT) scan. The lesion was believed to have occurred prenatally. He began receiving physical therapy at age 7 months. Physical therapy followed the task-oriented model of motor learning and included neurodevelopmental therapy (NDT) techniques and various therapeutic techniques to increase sensory awareness. He walked at age 15 months. The child initially received NMES to his upper extremity when he was only 19 months of age and to the lower extremity when he was 21 months of age.

At age 19 months, the child's upper-extremity function and regard were limited. He did not use the hand, and his arm was usually seen just hanging by his side; he rarely appeared to notice his left upper extremity. He could not creep on his hands and knees or play with the left hand. He often placed the back, not the palm, of the left hand on the supporting surface when he was placed in a quadrupedal position. The child could take some weight on the extended arm if given assistance to maintain elbow extension, but he would resist any assistance to creep. He would collapse and struggle to get out of the
by looking at the arm, but he made no attempt to remove the electrodes. The child immediately began to use the arm for the first time in creeping about the room unassisted, except for the use of NMES. He seemed very pleased and continued with creeping and moving to a sitting position and back to creeping for about 10 minutes until NMES was removed. Creeping was unexpected. He had never crept on his hands and knees unassisted and without much protesting when it was attempted. The low-amplitude NMES was able to assist in improving the child's muscle contraction and, probably, his sensory awareness.

Carryover occurred when NMES was removed. During the following week, the child continued to creep 0.3 to 0.6 m (1-2 ft) at home each day. Figure 2 shows his creeping style after only three weekly 15-minute sessions of NMES applied to the triceps brachii muscle. This dramatic improvement may be due to increased sensory awareness and augmented contraction of the muscle, as enough strength appeared to be present to permit the activity.

When low-amplitude NMES was added to the child's active weak muscle contraction, the resulting contraction was augmented. As discussed in this report and illustrated by the photographs, with NMES to augment the muscle contraction, the child was immediately able to perform activities that he had not done previously.

The sensory assistance of the vibrator coupled with the therapist's slight pressure against the arm would maintain the elbow extension when the child was on his hands and knees. When the vibrator or support was withdrawn, however, the elbow collapsed and the child could not remain on his hands and knees. With NMES augmenting the child's weak triceps brachii muscle contraction, no outside support was needed and the child was able to functionally succeed at creeping on his hands and knees for the first time.
The child's hand remained nonfunctional. He could bear weight on it, but when he tried to put something in the hand, the wrist remained flexed and the fingers did not often grasp. He needed to be able to use finger flexion and extension for grasp and release. He needed to use wrist extension to make grasp efficient and strong, as grasp is weak with the wrist held in flexion.

Figure 3 shows how NMES was used for various hand and wrist movement patterns. Initially, one NMES unit was used, with the electrodes on the dorsal surface of the arm stimulating the wrist extensors and those on the volar surface stimulating the finger flexors. Initially, the unit was set in a symmetrical mode so that both the wrist extensors and the finger flexors were stimulated simultaneously when the remote-control switch was used. When the switch was released, no stimulus was felt.

Five weeks after the initial use on the triceps brachii muscle, NMES was used to stimulate hand function. The child had not used wrist extension or both hands together. The electrodes were placed to stimulate the wrist extensors and finger flexors. He was given loosely fitted nesting barrels to play with to encourage him to use both hands together.

With NMES, the child immediately began to use both hands together, as shown by photographs taken during that first session. Figure 4 shows him using both hands together for the first time. With NMES stimulating the wrist extensors and finger flexors, he was able to separate the barrels. The carryover was maintained in the following week. The child appeared more aware of his left hand, and he could be encouraged fairly easily to use both hands together.

In the next 2 months, NMES was used for various movement patterns, depending on need. Observations of the child, combined with the parents' report on the results from the previous physical therapy visit, formed the clinical judgment for which muscle groups needed stimulation that day. Occasionally, when the child did not bring the arm forward, the anterior deltoid or triceps brachii muscle was stimulated. If he still did not use shoulder flexion or bring the arm forward, both muscles were stimulated. The wrist was usually stimulated during each visit, with electrodes added to other areas, depending on success. The wrist extensors and the finger flexors and extensors were often stimulated while the child played with manipulative toys. Two NMES units and two remote-control switches were used to accomplish this assist (Fig. 3). One unit stimulated the wrist extensors only. The other unit alternately stimulated the finger extensors and flexors. Each unit had a separate remote-control switch. As the child played, grasp or release could be facilitated without the therapist's hands constantly interfering with play. With NMES augmenting the muscle contraction, the child had enough muscle output to move the body part without needing assistance. This freedom to move and function gave the child a chance for better motor learning, including developing some anticipatory or feed-forward skills.

The child's functional abilities during the treatment session determined which muscles were facilitated. The setup shown in Figure 3 allows four different muscle groups to be used. The child was observed to determine which muscles he was using and which muscles were not being used. The three leads allow wrist extension
on one unit with another lead not being used. Sometimes the elbow extensors, shoulder flexors, or thumb abductors were stimulated. The lead on the unit with the lead to the wrist extensors was often used to stimulate the additional muscle. If the child's reaching was not adequate, the lead assisted the anterior deltoid muscle.

If the thumb tended to be held in the palm, the lead stimulated the thumb abductors. The stimulus was given simultaneously with the wrist extensors.

The child in case 1 used the wrist extensors much of the time but was not able to maintain finger flexion to hold on to an object. In Figure 5, he is shown using active wrist extension with NMES to assist in finger flexion and elbow extension while stacking interlocking toy blocks. The amplitude was low, just enough for him to feel the stimulus but not enough for him to be distracted.

Two months after beginning NMES, the child in case 1 extended his involved hand to his mother to wash after eating. This was the first time that he had extended his involved hand to his mother, as he had not previously used that hand when eating. It appeared that NMES was improving the child's sensory awareness. A month later, he was able to hold on to a toy golf club and maintain his grasp as he swung. He was also able to hold a plastic baseball bat with both hands and was sometimes able to maintain the two-handed grip at the end of the swing.

The child's thumb extensors and abductors were stimulated with NMES as he played with toys that motivated thumb movement. Figure 6 shows NMES used to increase extension and abduction of the thumb. The result was easier passive range of motion of the hand and thumb. The child showed good carryover, as he used the thumb intermittently during therapy when playing with and without NMES. The photograph shown in Figure 6 was taken 9 months after the initial use of NMES. Weekly NDT occupational therapy was added to the weekly physical therapy program when he was 24 months of age.

The child's abilities varied from week to week. Carryover from NMES lasted for a few days to an entire week. Task-oriented activities were chosen that were thought to be age-appropriate and of interest to him. Neuromuscular electrical stimulation was used to encourage the movement pattern or muscle group that was not being used.

At 25 months of age, the child made many gains after 6 months of once-weekly physical therapy with NMES. The most significant gain was increased awareness and spontaneous use of the left arm and hand. He was able to creep, climb, and use both hands together. His grasp and release were much improved. Disregard of the left extremity was no longer observed.

Case 2

The child in case 2 was a 6.7-year-old boy when he began receiving NMES to both the upper and lower extremities. He was diagnosed as having cerebral palsy due to sporadic oxygen deprivation at birth. A CT scan showed damage in the left hemisphere. At 10 months of age, he began twice-weekly sessions of tradi-
The object was put into the hand so that the fingers were placed around it, the flexor grasp reflex tended to keep the object in the hand for a short time. The child had to pull the object out of the hand, as release was not possible.

The child at 6.7 years of age received twice-weekly NMES sessions for 6 weeks, for a total of 10 visits, with a 2-week break in the middle. The NMES was given to the elbow extensors, wrist and thumb extensors, thumb abductors, and finger flexors during task-oriented activities. Suggestions for physical therapy activities were taken from Carr and colleagues.13-15

Initially, stimulation of the wrist extensors did not demonstrate even a trace contraction. The child did have feeling in the arm and was able to verbalize when the amplitude was high enough. After 2 weeks, a trace contraction was barely felt when NMES was used. Although the wrist did not actively extend except in a mass movement pattern, the child appeared to have more sensation, as shown by his increased use of the hand.

The photograph in Figure 9 was taken after seven sessions with NMES. The child appeared to have more awareness of the hand, and he was able to put the spinning top into the left hand and use both hands together to wind the top and press the button so that it could spin, without the use of NMES.

Spontaneous use of the hand improved. After the sixth session, the child spontaneously took an ice-cream cone in his right hand from his mother. After nine sessions, the photograph in Figure 10 was taken. His hands are on a hoop that he picked up and rolled back and forth before releasing it to send it rolling. As his hand awareness progressed, he continued to use it more for reaching and touching objects that he was passing, such as running his hand along a banister. He learned how to put items into the right hand to hold...
with a systems-model approach, the poor function and awareness of the arm and hand did not change until NMES was added to the program when he was 1.6 years of age. When that happened, he learned to creep and to use both hands together. His functional use of the hand and arm continued to progress with further use of NMES, and disregard of the hand and arm was no longer seen at 2 years of age.

The older child (case 2) had a hierarchical-model (NDT) physical therapy program from age 2 years until he was 6.8 years of age. At that time, he had lost the little skill that he had when he was 5 years of age. His upper extremity was not functioning, his hand appeared atrophied, and the right arm was noticeably smaller than the left arm. He had grown over the almost 2-year period, so it would be expected that biomechanical changes in the involved extremity could have some effect on the loss of function.\textsuperscript{16} It took four sessions of electrical stimulation of the wrist extensors before a muscle contraction could clearly be felt. After only 10 sessions of physical therapy with NMES, the child was spontaneously using his right (involved) hand, and occasionally he used the right hand independently to hold items.

**Recommendations**

The muscles of the hand are small, especially in children. I prefer to use a low pulse rate initially for treating children with cerebral palsy by use of NMES. A low rate, about 5 to 7 pps, is usually more comfortable to the child, and the amplitude can be higher. This produces a more discernable twitch that will allow the therapist to see whether the desired muscle is actually the one being stimulated or whether there is too much overflow.

Lack of coordination or sensory awareness of how to use the hand is often a major problem in a child with cerebral palsy.\textsuperscript{17} A low pulse rate may give enough sensory input to assist the child with function. Some children do not like the low rate. It is
Summary and Conclusions

Two children, both with hemiplegic cerebral palsy from birth, improved in upper-extremity function and awareness after the addition of NMES to their systems-model physical therapy program. The child in case 1, who began NMES at 1.6 years of age, showed immediate and surprising functional changes in both the upper and lower extremities that were more dramatic and rapid than those seen in the child in case 2 at almost 7 years of age.

The use of NMES demonstrated important functional changes with children with cerebral palsy that warrant further investigation. Preliminary findings suggest that NMES may be a useful physical therapy tool when used with a task-oriented model of motor learning. It would be of interest to learn whether electrical stimulation could enhance motor learning and control enough to increase function so that the biomechanical changes that occur with growth deficiencies would not occur. More studies are needed to determine whether NMES can benefit other children with upper motor neuron lesions.

Acknowledgments

I thank Herb Kieklak for his suggestions, including urging me to use NMES on young children and to consider working with the thumb. I also thank Medtronic Nortech Division for the loan of one of the NMES instruments, together with the necessary disposable electrodes, used in this research.

References


