NEUROMUSCULAR ELECTRICAL STIMULATION (NMES) has been shown recently to be a useful technique for producing increases in voluntary muscle strength during the rehabilitation of patients with spinal cord injury (Carroll, Bird, & Brown, 1992; Ferguson & Granat, 1992). Of equal if not greater significance than increases in strength, however, are the associated improvements in function. It is the function achieved as a result of muscular contractions that influences a patient's quality of life. The following case report describes how NMES was used successfully to improve the strength and endurance of the anterior and middle fibers of the deltoid muscle and so to enable a man with quadriplegia to feed himself.

Methods

Patient Profile

The patient was a 65-year-old retired electrician who was involved in a motor vehicle accident and sustained an incomplete C4 quadriplegia. After 2 weeks of conservative management, he commenced rehabilitation, which included daily sessions of occupational therapy and physical therapy. The emphasis in both therapies was to enable maximum independence by maintaining joint range of motion and by strengthening muscles under voluntary control.

Status of Recovery

The patient regained some limited voluntary muscle control below the level of C5 in the right arm but very little functional movement in the left arm. After 25 weeks of inpatient rehabilitation in the Spinal Injuries Unit, shoulder flexion and abduction of the right arm had improved from a trace (grade 1) to partial movement against gravity (grade 2); biceps brachii strength was fair (grade 3). This assessment was based on the Manual Muscle Test, which rates from no muscle activity (grade 0) to normal strength (grade 5) (Medical Research Council, 1943). Increased tone, predominantly in the right latissimus dorsi muscle, also complicated the pattern of voluntary movement; this was managed by various therapeutic techniques such as positioning, stretching, and mobilizing, as well as by 110 mg per diem of the pharmacological agent baclofen.

The patient's primary goal was to be independent in self-feeding, and it was hoped that his motor recovery would be sufficient to enable him to achieve this goal. However, the active range of movement at the shoulder was insufficient to allow him to bring his right hand to his mouth.

In an attempt to increase the strength and endurance of the shoulder flexors and abductors, the patient began a program of assisted shoulder movements using
the OB Help Arm\(^1\), a counterbalanced deltoid-assist sling (Trombly, 1982). The patient was able to feed himself using the counterbalanced sling (CBS) and a wrist support splint, but despite 3 weeks of training, further improvements were not forthcoming. The patient did not wish to try a mobile arm support as he did not like the appearance of the apparatus. In our experience, this attitude is not uncommon in people with disabilities, who often consider that negative aspects of such devices outweigh the positive aspects, namely the potential for increased independence.

In a further attempt to achieve independent feeding, a program of NMES was instigated. This program was performed jointly by the treating occupational therapist and a physical therapist who was researching the role of NMES in the rehabilitation of patients with spinal cord injuries.

**Assessment**

Before commencement of electrical stimulation, baseline measures of function were recorded on three separate occasions over a period of 8 days. The parameters measured were (a) the range of voluntary glenohumeral movement, (b) the proximity of the index finger to the mouth, and (c) a test of feeding endurance. The specific details of the assessments were as follows:

- **Voluntary glenohumeral movement.** Although not a pure anatomical action, the movement of flexion with abduction was selected, as it most closely resembled the movement of the humerus on the glenoid during the act of feeding. A Plurimeter V gravity-goniometer\(^2\) was attached to the patient's upper arm, midway between the planes of flexion and abduction, along the axis of the humerus. The goniometer dial was set at 0° while the patient sat resting in his powered wheelchair. The patient was then asked to lift his arm as high as he could as if he were drinking soup from a bowl. The maximum displacement of the humerus in this plane during this motion was recorded during each of three arm movements and the average of these attempts was calculated.

- **Proximity of hand to mouth.** The patient was asked to bring his hand to his mouth as if he were attempting to feed himself with a spoon. Forward flexion of the head and neck was not permitted as this was monitored closely by one of the therapists. The minimum distance between the lip crease and the tip of the index finger was recorded for each of three attempts. An average of the three attempts was calculated.

- **Feeding endurance.** Independence in feeding requires the successful completion of repeated upper limb movements. During our initial assessment, we observed that, although the patient could bring a spoon to his mouth when assisted minimally by the CBS, he fatigued quickly and required frequent rest periods between each maneuver. We, therefore, included a test of feeding endurance in our baseline assessment; this was measured by counting the number of times, in 90 sec, that the patient could take a spoon from a designated point on the table to his mouth while assisted by the CBS.

For all assessments on all three occasions, the patient's right hand was supported by an Orfit Thermoplastie wrist cock-up splint\(^3\) that maintained his wrist joint in approximately 20° of extension. During the feeding endurance test, the splint was used in conjunction with a palmar pocket into which a modified spoon was placed. Other factors, such as the height of the table, the position of the patient at the table, the powered wheelchair and cushion, the arrangement of the counterbalanced slings, the time of day, and the instructions given, were all carefully controlled by standardization across sessions.

**Treatment**

After the baseline measurements were completed, the patient commenced a program on NMES that was performed 5 days a week over a 3-week period. Reassessments were performed at weekly intervals. Specifically, the program consisted of 3 to 4 sets of 18 electrically assisted contractions of the right anterior and middle deltoid muscle. A 2-min rest period was given between sets. Two carbon rubber electrodes\(^4\), 4 × 10 cm, were positioned so that the cathode was over the middle deltoid, just below the lateral edge of the acromion, and the anode was positioned over the anterior deltoid muscle and bicipital groove. A muscle stimulator, the Myocare Plus Stimulation System\(^5\), was programmed to deliver asymmetrical biphasic pulses of 150 microsec at a stimulus frequency of 50 Hz. A maximum output of 80 mAmps was possible, but the intensity actually used during the treatment ranged between 60% and 85% of this value. The duty cycle was 7 sec on and 13 sec off with the on phase including an up ramp of 2 sec and a down ramp of 1 sec.

The patient was requested to lift his arm, as if he were trying to eat with a spoon, each time he felt the electrically evoked contractions commence. These exercises were performed while the patient sat in his powered wheelchair wearing a wrist support splint. Feeding practice with the counterbalanced sling was discontinued during the 4 weeks of the NMES program but the remainder of the rehabilitation program was unchanged.

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\(^1\)Manufactured by Parnt Trading, Box 154, S-198 00, Balsta, Sweden.

\(^2\)Manufactured by Dr J. Rippstein. G1-1093 La Conversion, Champs des Puteaux 53, Switzerland.

\(^3\)Manufactured by Orfit Industries, Vosved 9A, b 2110, WijNEGEM, Belgium.

\(^4\)Manufactured by Medtronic NorTech, 10237 Flanders Court, San Diego, CA 92121.

\(^5\)Manufactured by 3M Company, 3M Center, Minneapolis, MN 55444.
Results

Baseline assessments were performed on days 1, 4, and 8; the NMES program commenced on day 8 after assessment and concluded on day 25. Mid- and post treatment assessments were performed on days 12, 19, and 26. A consistent pattern was observed for the three parameters under study (see Figure 1). In each case, stable responses were recorded during the three baseline assessments; marked improvements were noted on day 12, after 4 exercise sessions. The scores from the day 19 assessment indicated that these levels had been maintained or had slightly improved. Further improvements were noted at the day 26 assessment. Specifically, when day 26 scores are compared with the mean baseline scores, measures of gleno-humeral movement and feeding endurance improved by 77% and 78% respectively; the hand to mouth proximity score decreased by 72%.

On day 15, the patient reported that he had developed a urinary tract infection. He complained of feeling very unwell and lethargic; a course of antibiotics was commenced. Despite this, the patient decided to continue with his NMES exercise program, although he found it more difficult to actively participate. He reported feeling "much better" on day 18. The lack of continued improvement observed at the day 19 assessment may reflect this complicating episode.

On day 24, after 12 exercise sessions, the patient reported that he could now place a spoon into his mouth independently. To test the functional value of this achievement, the patient was given his lunch, a plate of pasta, and he proceeded to eat three quarters of the meal without any assistance except for the wrist support and the palmar pocket. This was the first time in 6 months that the patient had been able to feed himself. Despite achieving our goal of independent feeding, the exercise program was continued until day 26 when the patient was discharged to a nursing home. It had been our intention to reassess the patient after 2 weeks without treatment; however, this was not possible. Staff members at the nursing home reported that, 6 months after the treatment, the patient continued to feed himself independently using a leather wrist support and palmar pocket splint.

Discussion

The single case study is a useful technique for evaluating the effect of an intervention in a clinical setting, even when complicating factors such as illness and sudden discharge unexpectedly arise (Payton, 1988). In this example, the motor deficits and the treatment goals related specifically to one person, so we were able to design both the assessment tasks and the exercise program to address these needs.

In recent years, NMES has been shown to have a role in the training of paretic muscles in neurologically impaired patients (Bajaj, Kralj, Turk, Benko, & Segal, 1989; Fields, 1987; Milner-Brown & Miller, 1988). Most attention has been focused, however, on the development of functional electrical stimulation systems for restoration of function (Peckham & Greasby, 1992). These systems, which activate muscles paralyzed by upper motor neuron lesions to provide functions such as respiration, hand grasp, ambulation, or bladder control, require sophisticated and expensive technical support, hence they are beyond the reach of most clinical facilities. With the exception of gait, which has been well studied (Bajaj et al., 1989; Bogataj et al., 1989; Merletti, Andina, Galante, & Furlan, 1979), researchers who have looked at clinical applications of NMES have generally considered only physiological parameters such as muscle strength or range of motion (Fields, 1987; Hansen, 1979; Seeger, Law, Cresswell, Stern, & Potter, 1989). Upper limb function, as a dependent variable, seems to have been ignored.

The purpose of this study was to evaluate the effect of an electrically assisted active exercise program on the attainment of a functional task, namely independent feeding. Our results show that this technique can produce marked and rapid improvements in active range of motion, endurance, and, hence, function in a patient who...
was otherwise not improving. There are several possible explanations for the improvement seen in the dependent variables. These include increased voluntary muscle strength, improved motor control, and decreased spasticity. On reviewing published literature, electrical stimulation of both paretic and paralyzed muscles has been shown by many researchers to produce increases in force or torque (Bajel et al., 1989; Glaser, 1986; Milner-Brown & Miller, 1988; Peckham, Marsolais, & Mortimer, 1980; Ragnarsson, Pollack, O’Daniel, Petrofsky, & Nash, 1988). The effect of NMES on spasticity in patients with either hemiplegia or spinal cord injury has also been studied widely but, conversely, conflicting claims of both increases and decreases in muscle tone have been reported (Yarkony, Roth, Cybulski, & Jaeger, 1992). Finally, the effect of NMES on patterns of motor control has not been been widely addressed. In one study of patients with hemiplegia, Fields (1987) used an electromyographically (EMG) triggered stimulator to train wrist extension and ankle dorsiflexion. He reported a trend towards increased peak EMG activity after training, which he interpreted as evidence of improved motor unit recruitment. Indeed, a comparison of biofeedback with NMES might identify the importance of increasing sensory feedback to facilitate motor unit recruitment in this group of patients. In summary, additional controlled studies of these and other factors would be required to identify the mechanisms behind the improved function described in this case report.

Conclusion

The functional gains achieved by NMES were sustained well after the conclusion of the treatment program. In this particular case, the patient continued to use his shoulder muscles frequently and regularly upon cessation of the training program. Had this not been so, it is probable that a rapid decline in range of motion and endurance would have occurred. The outcome described in this case report demonstrates how the skills of both physical and occupational therapists can be combined to achieve a specific goal. We believe that NMES is an underused resource that can hasten the return of voluntary muscle function in selected patients. Our findings add further strength to our previous recommendation that NMES-assisted exercise programs be incorporated into the rehabilitation programs of patients after incomplete spinal cord injury (Carroll et al., 1992).

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