

The Effects of Functional Electrical Stimulation on Shoulder Subluxation, Arm Function Recovery, and Shoulder Pain in Hemiplegic Stroke Patients

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ABSTRACT. Faghri PD, Rodgers MM, Glaser RM, Bors JG, Ho C, Akuthota P. The effects of functional electrical stimulation on shoulder subluxation, arm function recovery, and shoulder pain in hemiplegic stroke patients. *Arch Phys Med Rehabil* 1994;75:73-9.

• The purpose of this study was to evaluate the effectiveness of a functional electrical stimulation (FES) treatment program designed to prevent glenohumeral joint stretching and subsequent subluxation and shoulder pain in stroke patients. Twenty-six recent hemiplegic stroke patients with shoulder muscle flaccidity were randomly assigned to either a control group ($n = 13$; 5 female, and 8 male) or experimental group ($n = 13$; 6 female, and 7 male). Both groups received conventional physical therapy. The experimental group received additional FES therapy where two flaccid/paralyzed shoulder muscles (supraspinatus and posterior deltoid) were induced to contract repetitively up to 6 hours a day for 6 weeks. Duration of both the FES session and muscle contraction/relaxation ratio were progressively increased as performance improved. The experimental group showed significant improvements in arm function, electromyographic activity of the posterior deltoid, range of motion, and reduction in subluxation (as indicated by x-ray) compared with the control group. We concluded that the FES program was effective in reducing the severity of shoulder subluxation and pain, and possibly facilitating recovery of arm function.

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Shoulder subluxation and pain is a major and frequent complication in patients with hemiplegia.¹⁻⁴ As many as 80% of patients with cerebrovascular accident (CVA) have been reported to show shoulder subluxation.^{5,6} Immediately following an upper motor neuron lesion such as CVA the affected extremities become flaccid in approximately 90% of patients.⁷ The only structures left to protect and provide support for the glenohumeral joint at this stage are the joint capsule and ligaments. In the absence of muscle function, the pull of gravity on the arm will often cause the capsule to stretch, resulting in shoulder subluxation. Subluxation usually develops in the first few weeks following hemiplegia. The downward traction that the dependent arm imposes may cause damage to all supporting structures of the shoulder. This condition has been associated with increased pain along with an increased incidence of inappropriate autonomic responses (ie, sympathetic reflex dystrophy) in the upper extremity.⁸ Occasionally, when traction is applied, damage to the brachial plexus and other peripheral nerves may occur.⁹

The traditional treatment for shoulder subluxation is to

use some type of sling for arm support.^{2,3} Although the sling helps to decrease pain for some patients, this positioning of the arm interferes with functional activities. Another disadvantage of a sling is that the arm is frequently held in a flexed and adducted position, which may enhance the flexor synergy of the upper extremity. If tone returns, the flexor synergy can also interfere with arm function. A goal of therapy for these patients is to increase functional use of the upper extremity while reducing shoulder subluxation. Because a sling may prevent functional use and may not be effective in preventing subluxation, other techniques for treatment are needed.

Some investigators have used functional electrical stimulation (FES) to treat shoulder subluxation in stroke patients. Baker and Parker¹⁰ used FES-induced contractions of the flaccid shoulder muscles to reduce existing subluxation. They measured shoulder subluxation by taking an antero-posterior x-ray of both involved and uninvolved shoulders. Their results showed a significant decrease in the degree of shoulder subluxation, but most patients did not attain full reduction of subluxation after six weeks of FES. The failure to regain normal shoulder joint position may have been due to the degree of subluxation prior to FES. None of the patients were treated prophylactically with FES during the acute phase of recovery.

Anderson¹¹ suggested that if stretching of the joint capsule could be avoided during the acute and flaccid phase of neural recovery from stroke, many patients would develop sufficient muscular activity to maintain the glenohumeral joint in normal alignment after the recovery phase. Avoiding capsular stretching could reduce the incidence of chronic subluxation in stroke patients and potentially reduce the number

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Submitted for publication July 22, 1993. Accepted in revised form March 10, 1993. Supported by a grant from the Rehabilitation Research and Development Service of the US Department of Veterans Affairs (#B90-86AP).

No commercial party having a direct or indirect interest in the subject matter of this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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0003-9993/94/7501-0032\$3.00/0

of individuals experiencing pain or autonomic dysfunction in the hemiparetic upper extremity.^{1,2,8}

The overall goal of this study was to objectively evaluate the effectiveness of a FES treatment program designed to prevent glenohumeral joint stretching and subsequent subluxation and to facilitate recovery of the flaccid shoulder musculature in acute stroke patients.

METHODS

Subjects

After the informed consent document was signed, 26 recent hemiplegic stroke patients with shoulder muscle flaccidity/paralysis were randomly assigned to either a control group ($n = 13$; 5 female, and 8 male) or experimental group ($n = 13$; 6 female, and 7 male). The mean \pm SD height, weight, and age for the experimental group were 174 ± 7 cm, 76 ± 12 kg, 65 ± 13 years, and for the control group were 166 ± 10 cm, 78 ± 11 kg, and 69 ± 12 years, respectively. Time poststroke was 17 ± 4 days for the control group and 16 ± 5 days for the experimental group. Eight patients in the experimental group and 9 patients in the control group had left sided hemiplegia (right CVA); 5 patients in the experimental group and 4 patients in the control group had right sided hemiplegia (left CVA). Because the patients were randomly assigned to the two groups, the average levels of infarct for these groups were assumed to be similar. A preliminary medical evaluation provided information on the cardiac and medical history of each individual. A baseline electrocardiogram (ECG) and a detailed cardiac history review were completed for members of the FES group. Individuals with cardiac pacemakers were excluded. Patients with cardiac deficits, especially conduction problems, were monitored closely by ECG during the initial trials of the FES program.

Evaluations

All subjects were measured for arm function, arm muscle tone, posterior deltoid muscle electromyographic (EMG) activity, upper arm girth, shoulder lateral range of motion (SLROM) for assessment of pain in the involved shoulder, and subluxation (via x-rays of both shoulders). These evaluations were performed at three time periods: at the start of the program (T1); at the completion of the 6-week program (T2); and, 6 weeks after completion of the program (T3). To verify reliability and comparability of the test data, all measurements were performed on both the uninvolved and involved shoulders. In addition, all the subjects were evaluated multiple times during the course of the study, therefore each subject served as his/her own control for any changes in the measured variables (ie, within group), regardless of the level and the extent of the infarct. Finally, changes in the variables measured were compared between the experimental and control groups.

Active movement patterns to evaluate arm function, and active range of motion were tested using the modified Bobath assessment chart.¹² This involved the use of a standardized chart, which included criteria related to active range of motion for performing various shoulder and arm function tasks.

These evaluations were performed with the patient in supine, sitting, and standing positions. These tests were divided into three grades according to their degree of difficulty (ie, the number of muscles involved and complexity of the tasks), with tests for grade 1 being the easiest and those for grade 3 being the most difficult. This grading system limited the number of tests required for severely affected patients; the less severely affected performed more tests.

For the assessment of pain, SLROM was measured in both the involved and uninvolved side using a goniometer.¹³ Each subject was positioned supine on a padded table with the shoulder abducted to 45° , the elbow held at 90° of flexion, and the forearm pronated. The tester then laterally rotated the shoulder slowly to the threshold of pain. Subjects were asked to disregard any pulling sensation or tightness in the shoulder. An increase in the degree of SLROM was interpreted to mean less pain in the shoulder.

The arm muscle tone evaluations were done to document the subjects' recovery process from the flaccid to the spastic stage.¹⁴⁻¹⁶ For this, the patients were examined while in a comfortable position, and muscle stretch reflexes and passive muscle tone were assessed bilaterally and separately for upper extremities. Arm muscle tone was evaluated using a modified Gross clinical scales.¹⁴ These scales graded muscle tone from 0 to 4 according to the following criteria: 0, no increase in tone; 1, slight increase in tone manifested by minimal resistance at the end of the range of motion when the affected part was moved in flexion or extension; 2, more increase in tone throughout the range of motion, but the affected part was easily moved; 3, considerable increase in tone, but passive movement was difficult; and 4, affected part was rigid in flexion or extension. We modified these clinical scales by adding intermediate grade increments (eg, 0.5, 1.5, etc) in order to increase evaluation sensitivity.

Surface EMG activity of bilateral posterior deltoid muscles was evaluated while patients were sitting comfortably in a chair. These muscles were chosen for EMG measurements because of easy access by surface electrodes. An increase in the EMG activity of the involved posterior deltoid muscle could indicate the recovery of function from flaccidity, and possibly recovery of other shoulder muscles as well. Thus, we compared EMG activity for the hemiplegic side with that of the uninvolved side. The following grading system was used: 0, no EMG activity; 1, medium EMG activity; and 2, normal EMG activity (ie, comparable with the EMG activity on the uninvolved side). We modified these grades by adding intermediate grade increments (eg, 0.5, 1.5, etc) in order to increase evaluation sensitivity. Because the posterior deltoid is the primary muscle active during shoulder abduction to 90° , the patients were first asked to actively abduct his or her uninvolved shoulder to 90° , and the EMG activity was recorded as grade 2 (normal).⁵ Then they were asked to attempt the same motion for the involved side. Most patients were not able to do this task during the first evaluation due to flaccidity, but this capability tended to progressively increase with subsequent evaluations. [Therefore, EMG activities of the involved and uninvolved side for each patient was compared with him or herself throughout the study.] To assure the uniformity and reproducibility of the data, 90%

of the evaluations on tone, arm function, range of motion, and EMG activity were done by one investigator.

Anteroposterior x-rays of both shoulders were taken while subjects were sitting in an upright position, and their arms at their sides with no support for the involved shoulder. Three x-rays were taken at T1, T2, and T3. All x-rays were evaluated by the same designated investigator on a portable viewing box. No FES was performed for 24 hours before final x-ray was taken to eliminate possible short-term effects of facilitation.

Radiological Technique

A modification of the distance measured from a single anterior-posterior radiograph described by Prevost and colleagues¹⁷ was used. For this, three initial reference points were determined: central point of the glenoid fossa; central point of the humeral head; and most inferior and lateral point on the acromial surface of the acromioclavicular joint. The vertical component of the glenohumeral alignment (V) was determined by measuring the vertical distance between the acromial point and the central point of the humeral head. The horizontal component (H) was measured as the horizontal distance between the central points of the humeral head and the center of glenoid fossa.

Treatment

Both groups received conventional physical therapy as part of their treatment programs. The experimental group received additional FES therapy. A commercially available stimulator² and two surface electrodes were used. This device has adjustments for the on-off stimulation cycle and the intensity of stimulation, and a timer to start and stop the stimulation. The active electrode was placed over the posterior deltoid muscle and the passive electrode was placed over the supraspinatus muscle using a configuration that minimizes activation of the upper trapezius muscle (which can cause shoulder shrugging). Stimulation frequency was set at 35Hz to create a tetanized muscle contraction. FES intensity was set to obtain the desired motion of humeral elevation with some abduction and extension to pull the head of the humerus into the glenoid cavity. To provide consistent position and shoulder joint protection, all subjects were asked to use their wheelchair arm support whenever sitting, both between and during the FES sessions.

Duration of both the FES session (1.5 to 6 hours/d) and muscle contraction/relaxation ratio were progressively increased (10/12sec to 30/2sec ON-OFF) as performance improved. When a subject was able to complete a 6-hour period of stimulation without marked fatigue of the stimulated muscle groups, the OFF time decreased and ON time increased for the subsequent FES sessions in a stepwise fashion. Marked fatigue was defined as no visible muscle response with maximum stimulation. The subjects thus received FES of increasing duty cycle for the next 5 weeks of the study. Increases in stimulation time were attained by decreasing the OFF time by 2 second intervals every day to a minimum of 2 seconds OFF. The goal ratio for ON-OFF time was 30:2. Subjects were assessed daily for muscle fatigue as

indicated by a lack of full reduction of the subluxation (by manual palpation) during full intensity FES. Those who demonstrated full FES-induced subluxation reduction throughout the 6-hour session progressed to the next step of ON-OFF ratio. These FES sessions were conducted 7 days/week for a total of 6 weeks. Conductive rubber electrodes with gel and tape were changed daily in order to ensure low impedance contact.

Statistical Analysis

Multivariate repeated measures analysis of variance was used to compare the two groups, experimental and control, and the three measurement periods T1, T2, and T3. Before performing the analysis, formal diagnostic procedures were followed. No serious departures from the assumptions necessary for the analysis were found. Therefore, the data for SLROM, H & V component of the x-ray results, and the girth were analyzed using the above stated technique. Values were normalized using the differences between the unaffected and affected side (unaffected-affected). Because the three variables of tone, EMG, and arm function were measured using an ordinal scale, we used the Wilcoxon rank-sum test for nonparametric statistical evaluations to compare the two groups.¹⁸ For all statistical testing, the .05 level of probability was required for significance.

RESULTS

For the uninvolved arms of both groups, there were no significant changes in any of the variables during T1, T2, and T3 evaluation periods. Results of the arm function, muscle tone, and posterior deltoid EMG activity measurements for the involved arm are shown in figure 1. Both groups initially were flaccid, demonstrating no arm function. After treatment, the experimental group showed increased arm function, tone, and EMG activity, which was significantly higher than the control group ($p < 0.05$). At follow-up, both groups showed increases in all three variables that were higher in the experimental group (although not significantly different, $p > 0.05$). Involved arm girths more closely matched the uninvolved girths for the experimental group over the study period although the decreased girth in the control group was not significant.

The average SLROM for the stroke-affected shoulder for both FES and non-FES groups was less than that for the unaffected shoulder. For the experimental FES group, the magnitude of the differences between the affected and unaffected side increased marginally ($p > 0.05$) over different time periods (21°, 24°, and 34° at T1, T2, and T3, respectively), whereas for the control non-FES group it increased significantly (19°, 43°, and 50° at T1, T2, and T3, respectively, figure 2). Thus the average difference in SLROM between the involved and uninvolved limb was significantly higher for the control non-FES group (indicating more pain) than for the experimental FES group. Overall absolute SLROM for the affected side remained higher for the experimental FES group during T2 and T3 (less pain) than for the control non-FES group.

X-ray evaluations of V indicated that changes over time differed significantly between the two groups (p value

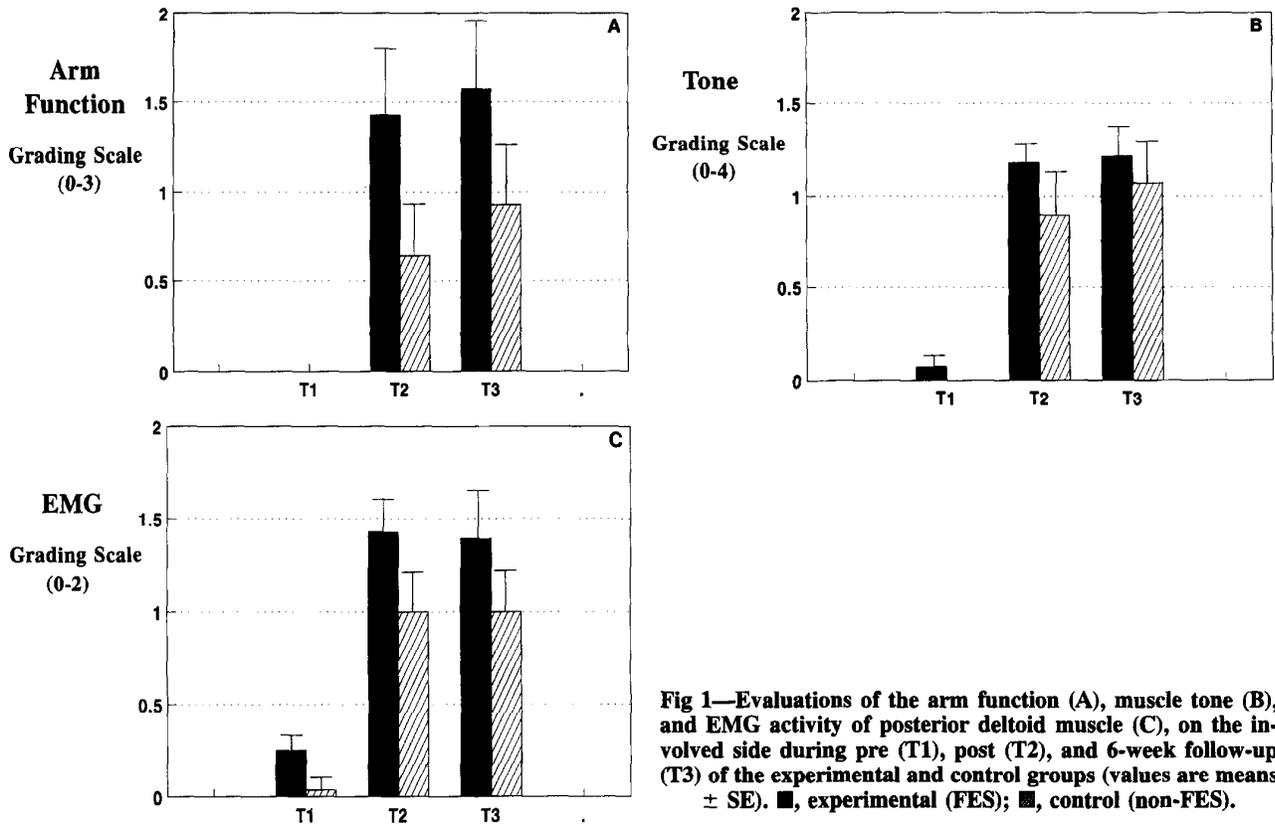


Fig 1—Evaluations of the arm function (A), muscle tone (B), and EMG activity of posterior deltoid muscle (C), on the involved side during pre (T1), post (T2), and 6-week follow-up (T3) of the experimental and control groups (values are means ± SE). ■, experimental (FES); ▨, control (non-FES).

= 0.0001). The average differences in V between the stroke-affected and the unaffected shoulder for the experimental FES and control non-FES groups are shown in figure 3.

These differences decreased significantly from 6.0mm in time period T1 to 2.46mm in time period T2 (reduced subluxation) and increased marginally ($p > 0.05$) to 3.46mm

in time period T3, whereas for the control non-FES group it increased significantly from 4.0mm to 9.85 in T2 (increased subluxation) and decreased marginally ($p > 0.05$) 9.35mm in T3. These results remained the same when comparing only the measurements on the stroke-affected side instead of the differences between the affected and unaffected side for the SLROM and V values. There were no significant

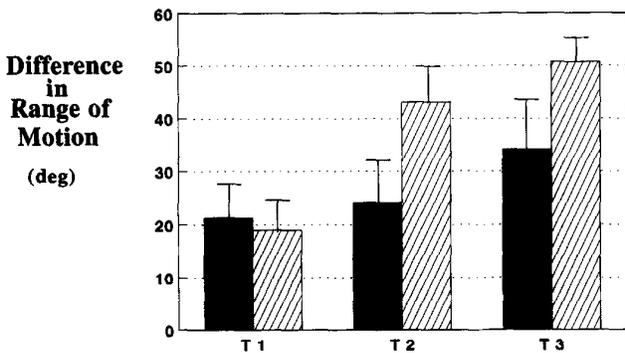


Fig 2—Differences between the involved and uninvolved upper extremity using shoulder lateral range of motion (SLROM) as an indication of shoulder pain in experimental FES and control non-FES groups during pre (T1), post (T2), and 6-week follow-up (T3) evaluations. Greater differences in SLROM between the involved and uninvolved shoulders indicate more pain in the involved shoulder (values are means ± SE). ■, experimental (FES); ▨, control (non-FES).

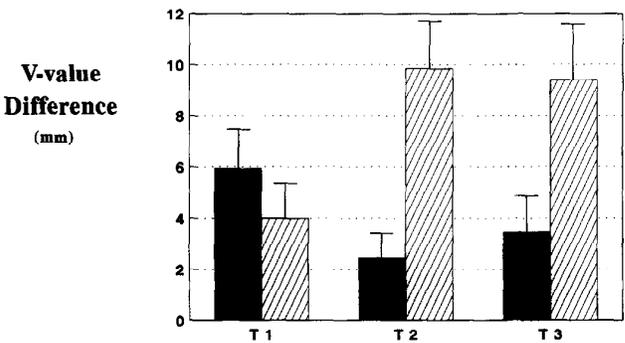


Fig 3—Differences between the involved and uninvolved upper extremity x-ray measurements using V values as an indication of shoulder subluxation in experimental FES and control non-FES groups during pre (T1), post (T2), and 6-week follow-up (T3) evaluations. Greater differences in V values between the involved and uninvolved shoulders indicate more subluxation in the involved shoulder (values are means ± SE). ■, experimental (FES); ▨, control (non-FES).

changes in the H values for either stroke-affected or nonaffected shoulders in both groups. Figure 4 shows an x-ray evaluation of the involved shoulder from an experimental subject before and after 6 weeks of FES treatment.

DISCUSSION

The incidence of shoulder pain in hemiplegic patients varies, but has been found in 80% of patients in some investigations.¹⁹⁻²¹ This is a frequent and debilitating symptom whose treatment remains a constant problem. Many health professionals have become concerned with shoulder pain because it interferes with rehabilitation, produces insomnia, requires added medications, and decreases the overall quality of life of many patients.²²⁻²⁶ Approximately 90% of those who suffer a stroke initially demonstrate a flaccid upper extremity.^{7,21} The lack of muscular support for the arm against gravity found in these patients can stretch the shoulder joint capsule and surrounding structures, such as the brachial nerve.²⁷ During this stage of absent muscle function, prolonged and progressive stretching of the capsule will frequently result in



Fig 4—The reduction of shoulder subluxation is evident in the x-ray evaluation of the involved shoulder from an experimental group subject before and after 6 weeks of FES treatment (values are means \pm SE).

irreversible damage to the joint capsule as well as shoulder subluxation.

The supraspinatus and posterior deltoid muscles are the most important muscles for maintaining shoulder joint stability. The mechanism of action of the supraspinatus muscle is that it (1) seats the head of the humerus into the glenoid fossa, (2) slightly abducts the humerus, and (3) externally rotates the arm. Both the capsule and supraspinatus muscle are horizontally aligned and prevent the head of the humerus from gliding down the glenoid fossa. The basic action of deltoid muscle contraction is elevation of the humerus along a line parallel to the humerus, which tends to force the humeral head up against the coracoacromial ligament. Depression of the glenoid fossa, as a result of downward rotation of the scapula, causes adduction of the arm and, therefore, requires muscular effort to support the arm. This may well be a significant factor contributing to subluxation and painful dysfunction of the hemiplegic shoulder.

After the initial stage of flaccidity, the patient typically goes through the second stage of recovery, which is spasticity. During this phase, involuntary contraction of the supraspinatus and deltoid muscles can assist in maintaining the stability of the glenohumeral joint. With further recovery, some voluntary function returns that permits volitional response to loading the involved arm. There is a direct relationship between the flaccid supraspinatus muscle and subluxation. EMG studies have shown that in hemiplegic patients whose flaccid supraspinatus muscle began to respond to loading the involved dependent arm by spasm or voluntary function (second and third stages of recovery after stroke), subluxation did not occur.^{21,28,29} However, if the superior capsule was allowed to become overstretched, the flaccid supraspinatus muscle could not respond to downward loading, and subluxation persisted even though spasticity and muscle activity returned later.

Therefore, early intervention may be an important factor in the treatment of the subluxation during the flaccid stage of stroke recovery. Potential advantages of early use of FES over traditional therapy (ie, sling) may include (1) the joint can be held together by induced contraction of muscle instead of a sling; (2) improved functional mobility may result with the elimination of the sling; (3) the FES-induced contractions of the flaccid supraspinatus and posterior deltoid muscles may exercise these muscle and quicken their recovery process, therefore, they can respond to the loading of the arm faster and prevent overstressing of the capsule.

The results of our study suggest that therapeutic FES intervention can be used to decrease shoulder subluxation and associated pain and maintain joint stability in hemiplegic stroke patients. Although both the experimental and control groups had spontaneous neurological improvement, the improvements appeared to have been enhanced by the FES treatment. This is evident by significant improvements in the arm muscle tone, function and EMG activities of the posterior deltoid muscle in our experimental group. Increases in the EMG activity and voluntary function for this muscle suggest that similar changes may have occurred in the supraspinatus muscle, which was also FES-trained. Indeed, the FES treatment may result in faster recovery of these muscles

by preventing the disuse deterioration that typically occur during the flaccid stage of recovery. It appears that after FES is discontinued, these muscles are strong enough to maintain joint stability and alleviate the need for further FES treatment, as evidenced by the follow-up evaluations of the FES experimental group. Because the subjects were randomly assigned to the control and experimental groups regardless of the extent and the side of the infarct, we believe that the mechanism to improve tone, function, and EMG in the experimental group is primarily due to peripheral improvements (ie, in the muscles themselves) as caused by exercise training of the stimulated muscles. We have no evidence that FES can improve central neural function for controlling the involved muscles.

The changes observed in the x-ray evaluations in the experimental group were toward reduced subluxation. This might be due to increases in tone and function of the supraspinatus and posterior deltoid muscles via FES training, because the actions of these muscles include humeral elevation and abduction. Furthermore, application of FES to these muscles caused the shoulder to be positioned with less adduction and internal rotation, which may have prevented stretching of the joint capsule and subsequent contractures.^{3,13} Another mechanism for prevention of subluxation during the FES treatment is that FES may have served as a biofeedback mechanism by which the patients learned appropriate protective behavior. Because many stroke patients tend to have attention deficit toward the flaccid/paralyzed side, FES may have caused them to pay more attention to correct positioning of their affected shoulder during recovery.

Although FES-induced contractions of shoulder muscles can pull the head of the humerus into the glenoid fossa to reduce subluxation, it is unclear as to the precise mechanism(s) for maintaining this effect when FES is removed. This was demonstrated during T2 x-ray evaluation when no FES was applied, and at the follow-up x-ray evaluation when FES had not been applied for 6 weeks. We hypothesize that as the result of FES activation of supraspinatus and posterior deltoid muscles, there was less deterioration and faster recovery of muscle function. Thus, these muscles themselves responded to the downward loading of the affected arm earlier in the experimental FES group and appeared to maintain joint stability, alleviating the need for further FES. This theory agrees with previous studies that found that if the glenohumeral joint can be held together as early as possible after a stroke, by the time muscle function returns these muscles can hold the arm together and prevent subluxation.

CONCLUSION

The results of our study agree with previous suggestions^{1,2,8,11} that if stretching of the joint capsule could be avoided during the acute/flaccid phase of neural recovery, stroke patients may develop sufficient muscular activity to maintain the glenohumeral joint in normal alignment after the recovery phase.^{5,21} The avoidance of capsular stretching could reduce the incidence of chronic subluxation of stroke patients and potentially reduce the number of individuals

experiencing pain or autonomic dysfunction in the hemiparetic upper extremity. Also, FES may result in faster recovery of arm function in these individuals. Although these results are encouraging, we were not able to completely alleviate the pain and subluxation in our experimental group. Further studies are necessary to investigate the use of longer periods of FES (ie, modify the FES protocol) and the FES of additional muscles for improving arm function and accelerating the recovery process.

Acknowledgments: The authors gratefully acknowledge the contributions of Vivien Corrado, RN, MS, for her technical assistance and the Miami Valley Hospital Radiology Department, especially Mehdi Ghaeri, MD, and Brenda Miller, RT, for their radiological assistance.

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