Relationship Between Functional Electrical Stimulation Duty Cycle and Fatigue in Wrist Extensor Muscles of Patients with Hemiparesis

ROBERTA PACKMAN-BRAUN

The purpose of this study was to investigate, in a sample of patients with hemiparesis secondary to cerebrovascular accident, the relationship between the ratio of stimulus on time to off time and muscle fatigue using a commercial electrical stimulation unit. An experimental model was used to test the hypothesis that the smaller the stimulus off time relative to stimulus on time, the greater will be the muscle fatigue over time. The wrist extensor muscles of 18 patients with hemiparesis were stimulated electrically, and isometric force output was recorded continuously using an adapted strain gauge-recorder apparatus. For each testing session, peak on time of the electrical stimulus was set at 5 seconds, and off time was set at 5, 15, or 25 seconds. Six randomly assigned treatment groups participated in three separate treatment sessions in a different order at 48-hour intervals. Treatment sessions were continued either until wrist extensor muscle force output decreased to 50% of its initial value or for a maximum of 30 minutes. Data analysis revealed that significant differences in muscle tension developed among all duty cycles ($p < .01$). Duty-cycle ratios of 1:1, 1:3, and 1:5 were shown to be progressively less fatiguing. Within the limits of this investigation, the 1:5 duty-cycle ratio was determined to be the best suited for initial use in programs of prolonged stimulation to the wrist extensor muscles of patients with hemiparesis. The hypothesis was accepted that the smaller the stimulus off time (rest interval) with respect to the stimulus on time, the greater will be the muscle fatigue over time.

Key Words: *Electrotherapy, electrical stimulation; Fatigue; Hemiplegia, general; Physical therapy.*

Neuromuscular electrical stimulation has been used to treat patients with intact peripheral nervous systems to increase muscle strength,[1,2] prevent muscle atrophy,[3,4] improve or maintain range of motion,[5,6] reeducate muscles,[7,8] reduce edema,[9,10] and provide orthotic support.[11,12] Although portable functional electrical stimulation units are readily available to the physical therapist, standardized guidelines for setting the characteristics of stimulation are unavailable. The purpose of setting these variables is to optimize the quality of the muscular response elicited. Treatment programs using FES involve the repetitive production of muscular contractions. The quality of the motor response elicited with an FES unit, therefore, must be considered, with reference not only to a single contraction but also to numerous successive contractions over the course of the treatment. Electrically stimulated contractions tend to be more rapidly fatiguing than volitional contractions because of their synchronous pattern of motor unit recruitment and the preferential stimulation of large diameter neurons innervating fast-fatiguing muscle fibers.[13] Optimizing the adjustable stimulation characteristics to minimize fatigue, therefore, is necessary to produce repeated muscular contractions with FES.

The literature on the electrical stimulation of muscles contains few descriptions of methods of determining the *duty cycle*, operationally defined here as the ratio of peak stimulus on time to stimulus off time. One of the few available studies on the subject involved a 1-second on time and a single-session recording of stimulation to the dorsiflexion musculature in a subject with hemiplegia.[13] Analysis of the data revealed that fatigue of the dorsiflexion musculature occurred more rapidly at a 1:1 duty-cycle ratio than at ratios of 1:3 or 1:5 and that the 1:3 ratio was more fatiguing than the 1:5 ratio. Kots used a 10-second on time to investigate the effect of the duty cycle on muscle fatigue in a group of wrestlers.[14] The stimulus frequency used was very high (exceeding the range available on portable, battery-operated FES units). Ratios of 1:1, 1:2, 1:3, 1:4, and 1:5 were compared for effects on force output over a series of 10 muscle contractions. Analysis of his results revealed that duty cycles of 1:1, 1:2, 1:3, 1:4, and 1:5 were less fatiguing progressively. Subsequent investigators[2,15] based their choice of similar stimulation characteristics, 10-second on time with 50-second off time, on the work by Kots. Other investigators have used various on-off ratios. Axelgaard and Brown, for example, used a 4-second on time with a 6-second off time[16]; Currier et al[17] used a 6-

---

R. Packman-Braun, MEd, is Clinical Specialist, Department of Physical Therapy, Moss Rehabilitation Hospital, 12th St and Tabor Rd, Philadelphia, PA 19141 (USA). She was a student in the master's degree program in exercise physiology, Department of Physical Education, Temple University, Philadelphia, PA, when this study was conducted in partial fulfillment of her master's degree requirements.

This study was funded in part by Medtronic, Inc, Neuro Division, Minneapolis, MN 55432.

This article was submitted June 30, 1986; was with the author for revision 21 weeks; and was accepted April 16, 1987. Potential Conflict of Interest: 1.

second on time with a 10-second off time; Eriksson and Haggmark[3] and Vodovnik et al[18] used a 5-second on time and a 5-second off time; Merletti et al[19] used a 1.5-second on time with a 3-second off time; and Bowman et al[7] used a 6- to 8-second on time with a 20-second off time. (In some instances, a slowed rise time, that is, a gradual movement from baseline to peak amplitude, may have been included in the reported on time.)

Clarification of guidelines for setting the stimulus duty cycle, with respect to minimizing fatigue, would improve current treatment protocols and help to ensure that research on the various therapeutic effects of treatment with FES will not be undermined by a poor choice of stimulation characteristics. The purpose of this study was to investigate, in a sample of patients with hemiparesis secondary to cerebrovascular accident (CVA), the relationship between stimulus duty cycle and muscle fatigue using a commercial FES unit. The hypothesis that the smaller the stimulus off time with respect to stimulus on time, the greater would be the muscle fatigue over time was tested at the .01 level of significance.

METHOD

Subjects

Eighteen patients (10 men, 8 women) with hemiparesis participated in the study. All patients or their family members gave their written, informed consent to participate in the experiment. The study and the informed consent statement were approved by the human subjects and research committees at both participating rehabilitation hospitals. The patients' ages ranged from 48 to 88 years, with a mean age of 67 years. Length of time from CVA varied from 1 month to 4 years, with 78% of the patients less than 3 months post-CVA. All patients were able to attain full joint excursion through the available wrist extension ROM with the application of FES. None of the patients had received electrical stimulation to the wrist extensor muscles at any time before the study.

Instrumentation

The Respond II® FES unit* was used to provide the electrical stimulus. Stimulus intensity and pulse frequency were determined for each patient before the first test session and then used in all subsequent sessions. Mean values for these characteristics were 40 mA and 36 pulses per second, respectively. Other stimulation characteristics used were 1) asymmetrical balanced biphasic square waveform; 2) constant current output; 3) pulse width fixed at 300 μsec; 4) rise time of 2 seconds; 5) fall time set at 0 seconds; 6) on time set at 7 seconds to include a 2-second rise time and a 5-second peak on time; and 7) off time set at 5, 15, or 25 seconds to provide duty-cycle ratios of 1:1, 1:3, or 1:5, respectively, with regard to the 5-second peak on time. Session length was either determined by the amount of time required to reach the point of fatigue (defined as 50% of the initial force output) or a 30-minute maximum treatment period (chosen to approximate an initial treatment length). An oscilloscope† and current meter‡ were used to verify settings of stimulation variables whenever adjustments were made.

An adapted strain-gauge recorder apparatus was used to measure muscle force. It consisted of a tension load cell§ with a 20-lb‖ capacity mounted beneath a wooden forearm support platform and a wrist restraint bar designed to rest on the dorsum of the hand (Fig. 1). The restraint bar prevented wrist extension past neutral, and forces applied in an upward direction against the restraint bar were transmitted to the tension load cell (Fig. 2). An MTI signal conditioner amplifier# was used to supply voltage to the force transducer, to amplify the signal, and to provide a variable voltage output to a Pederson strip chart recorder.**

Calibration Procedure

A single investigator (R.P.) performed the calibration procedure on the testing apparatus once in the morning and again before the afternoon recording session of each test day. The calibration apparatus consisted of a distraction scale†† suspended between the crossbar of a tower attached to the forearm support platform and a hook on top of the wooden wrist restraint bar (Fig. 3). A minimal amount of tension (2 lb) was placed on the scale and on the tension load cell by tightening the wing nut on the screw from which the scale was suspended. The controls of the amplifier and recorder were adjusted to read zero at this degree of tension. The wing nut on the screw suspending the scale then was tightened to produce a tension of 4 lb on the scale and, thus, on the wooden wrist restraint bar of the forearm support platform. The recorder sensitivity was adjusted so that this amount of tension was transmitted through the amplifier to produce a movement of the recording pen corresponding to a specific line on the graph paper. The wing nut was tightened in 2-lb increments to check for an equal degree of recorder pen deflection. The wing nut then was loosened gradually until the testing apparatus was calibrated, and the calibration apparatus was removed from the forearm support platform. Pressure exerted on the restraint bar was varied to observe for responsive movement by the strain gauge-recorder apparatus.

Testing Procedure

Each patient participated in three separate testing sessions at 48-hour intervals (Monday, Wednesday, and Friday). To further minimize the influence of cumulative training or fatigue effects on the study's results, the three duty cycles were administered randomly to equal numbers of patients in each of the six different treatment sequences (eg, 1:1, 1:3, 1:5; 1:1, 1:5, 1:3; 1:1, 1:5). Subjects were assigned to the six protocol sequences in a randomized manner.

Immediately before the initial testing session, electrode placement, stimulus intensity, and pulse repetition rate were established for each subject. The skin on the dorsal forearm first was cleansed with alcohol. Salt-free gel was used as a transmission medium during the pretesting and testing sessions. Two 2- × 2-in‡‡ carbonized rubber electrodes were placed over the areas on the dorsal forearm identified for stimulation of the wrist extensor muscles by Benton et al.[13]

* Medtronic, Inc, Neuro Div, 7000 Central Ave NE, PO Box 1250, Minneapolis, MN 55440.

† Model 323, Sony Corp of America, 1 Sony Dr, Park Ridge, NJ 07656.

‡ Model 270, Series 5, Simpson Electronic Co, 853 Dundee Ave, Elgin, IL 60120.

§ Stress and Test Corp, PO Box 828, Exton, PA 19341.

‖ 1 lb = 0.4536 kg.

Model 1600, MTI Corp, 1102 S Broom St, Wilmington, DE 19805.

** Model 27MR, Pederson Instruments Inc, 3018 Scott Blvd, Santa Clara, CA 95050.

†† John Chatillon & Sons, 83-30 Kew Gardens Rd, Kew Gardens, NY 11415-1999.

‡‡ 1 in = 2.54 cm.

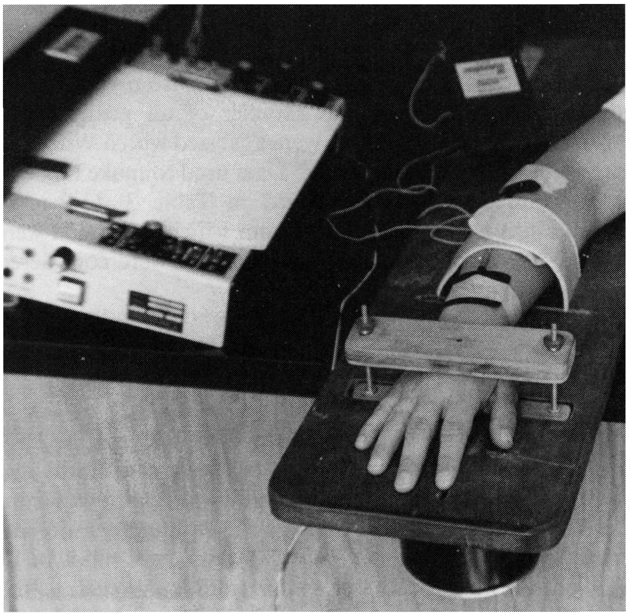

Fig. 1. Subject with arm in place on wooden forearm support platform of adapted strain gauge-recorder apparatus (Velcro straps not shown in proper orientation to allow view of electrodes).

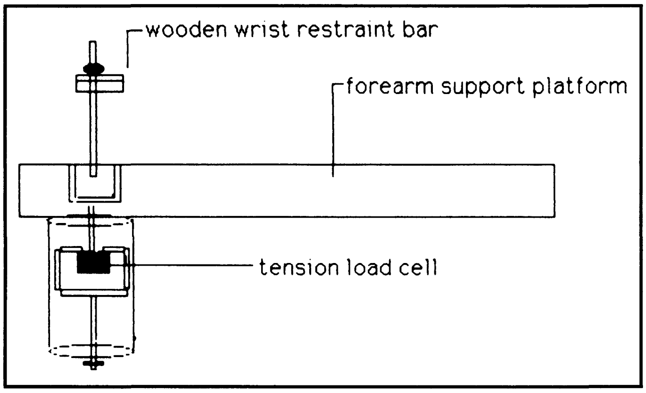

Fig. 2. Lateral view of schematic representation of forearm support platform with adapted strain gauge-recorder apparatus.

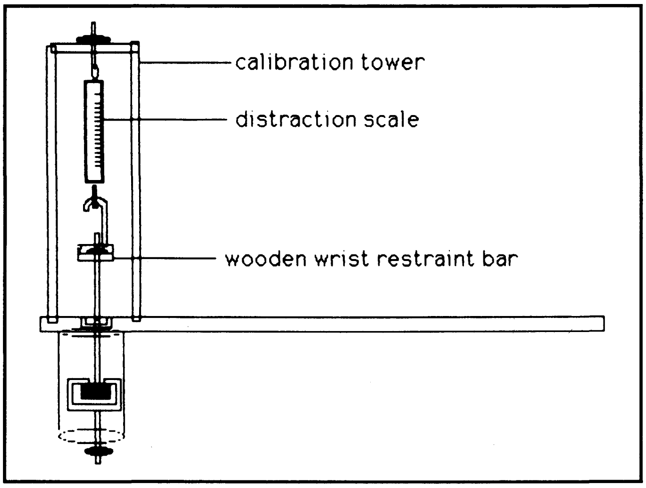

Fig. 3. Lateral view of schematic representation of calibration apparatus.

The active electrode was placed close to the lateral epicondyle of the humerus. The dispersive electrode was placed just proximal to the wrist. To locate motor points, the electrodes were moved over these designated areas until a strong, balanced wrist extension contraction was achieved. Electrode placements then were marked with a surgical skin pencil for use in subsequent testing sessions. Current intensity was determined by gradually increasing current flow until a muscle contraction was achieved that met two criteria: 1) It could move the wrist through its available extension ROM and 2) it could, with the wrist fully extended, hold against minimal resistance applied to the dorsum of the hand into pure flexion. Pulse repetition rate was set to be just tetanizing. Stimulus frequency and intensity were recorded for use in all testing sessions. This unit then was turned off, and a 10-minute rest interval was provided.

During each testing session, the patient's involved upper extremity was prepared for electrical stimulation of the wrist extensor musculature. After cleansing of the skin with alcohol, gel was applied over the predetermined stimulation points and the electrodes were secured with paper tape.

With the electrodes in place, the arm was positioned on the wooden forearm support platform so that, with the wrist in the neutral position, the wrist restraint bar rested on the dorsum of the hand just proximal to the metacarpophalangeal joints. The forearm then was secured to the platform with Velcro proximally and distally. The nuts of the screws attaching the wrist restraint bar to the forearm support platform were tightened to achieve a slight degree of tension on the load cell, and the recorder was adjusted to read zero at this setting.

Contractions of the wrist extensor muscles were elicited using the FES unit. Stimulus frequency was adjusted to duplicate the values established during the pretesting session. Stimulus peak on time was set at 5 seconds, and off time was set at 5, 15, or 25 seconds. The intensity was adjusted to provide the predetermined force output, and the recorder was turned on and adjusted to the appropriate sensitivity. The force of the cycling muscle contractions was measured continuously and recorded over the course of each session by the adapted strain gauge-recorder apparatus. Each session lasted 30 minutes (maximum) or until force output decreased to 50% of its initial value. At all test sessions, the same investigator (R.P.) positioned the patient's forearm, wrist, and hand on the forearm support platform; adjusted the wrist restraint bar; set the stimulation characteristics; and timed the stimulation sessions.

Data Analysis

The data were analyzed to determine whether the onset of fatigue was affected by the duty cycle. Raw data for onset of fatigue for each patient are contained in Table 1. The onset of fatigue was recorded as >30 minutes rather than as an absolute time value for those patients whose force output had not decreased to 50% of the initial value within the 30-minute maximum time limit of each treatment session. To use the data of these patients, a relative ranking procedure was used for the three protocols with respect to the production of fatigue. Ranks for each patient under each of the test conditions are contained in Table 2. The Friedman two-way analysis of variance (ANOVA), analogous to a one-way ANOVA for repeated measures, was used to test the null hypothesis that no difference exists among the sets of data associated

TABLE 1
Time (in Minutes) for Force Output to Decrease to 50 Percent of Its Initial Value at Various Duty-Cycle Ratios

Patient Number	Duty-Cycle Ratio		
	1:1[a]	1:3[b]	1:5[c]
1	11.0	14.3	22.0
2	9.9	>30.0	>30.0
3	5.0	25.3	13.2
4	5.5	11.7	23.7
5	6.6	25.3	>30.0
6	5.0	11.0	17.1
7	11.0	9.9	>30.0
8	5.0	6.3	>30.0
9	5.1	14.7	16.2
10	6.4	>30.0	>30.0
11	5.0	8.1	>30.0
12	10.5	15.8	>30.0
13	5.0	5.0	8.8
14	5.0	13.9	>30.0
15	5.0	11.4	28.1
16	12.4	>30.0	>30.0
17	5.0	14.7	24.8
18	14.4	>30.0	>30.0

[a] 5 seconds on; 5 seconds off.
[b] 5 seconds on; 15 seconds off.
[c] 5 seconds on; 25 seconds off.

TABLE 2
Ranking[a] of the Three Duty-Cycle Ratios with Respect to Onset of Fatigue for Each Patient

Patient Number	Duty-Cycle Ratio[b]		
	1:1	1:3	1:5
1	1	2	3
2	1	2.5	2.5
3	1	3	2
4	1	2	3
5	1	2	3
6	1	2	3
7	2	1	3
8	1	2	3
9	1	2	3
10	1	2.5	2.5
11	1	2	3
12	1	2	3
13	1.5	1.5	3
14	1	2	3
15	1	2	3
16	1	2.5	2.5
17	1	2	3
18	1	2.5	2.5

[a] 1 is most rapidly fatiguing; 3 is least rapidly fatiguing.
[b] Refer to Table 1 for timing of ratios.

TABLE 3
Summary Statistics from Wilcoxon Matched-Pairs Signed-Ranks Test

Condition Comparison[a]	Number of Pairs[b]	Total of Ranks with Less Frequent Sign
1:1 vs 1:3	17	0
1:3 vs 1:5	13	−6.5
1:1 vs 1:5	18	0

[a] Refer to Table 1 for timing of ratios.
[b] Only pairs with differences were considered.

with the three duty cycles.[20] Findings were considered to be significant at the $p \leq .001$ level.

Additional testing was performed to establish whether each condition tested was statistically different from each of the others. Two-group correlated samples of all possible pair combinations of the three sets were analyzed with a Wilcoxon matched-pairs signed-rank test.[20] Data used to make the Wilcoxon comparisons are contained in Table 3. Individual patient ranks for each condition from which these data were derived are contained in Table 2. Findings were considered to be significant at the $p \leq .01$ level.

RESULTS

Results of the Friedman two-way ANOVA and the Wilcoxon matched-pairs signed-ranks test were statistically significant.[20] Each test condition was found to be different from the others. Table 2 shows that the 1:5 duty-cycle ratio was less fatiguing than either of the other duty-cycle ratios in 13 (72%) of the 18 patients tested; in 4 additional patients, the 1:5 and 1:3 ratios were tied as the least fatiguing duty-cycle ratio. The 1:1 ratio was more fatiguing than either of the other duty-cycle ratios in 16 (89%) of the 18 patients tested; in 1 additional patient, the 1:1 and 1:3 ratios were tied as the most fatiguing duty-cycle ratio. In general, the longer the rest period with respect to the stimulation on time, the less was the fatigue noted over time.

Figure 4 shows that no subject was able to complete the desired 30-minute treatment session at >50% of initial force output at the 1:1 duty cycle ratio; however, 4 patients (22%) were able to complete the session at the 1:3 duty-cycle ratio, and 10 patients (56%) successfully completed the session at the 1:5 duty-cycle ratio. Seventy-eight percent of the subjects maintained a force output of >50% of the initial value for more than 20 minutes at the 1:5 ratio.

DISCUSSION

Analysis of the results of this study shows that the duty-cycle ratio is an important factor affecting the onset of muscle fatigue. Longer stimulus off times with respect to stimulus on time were associated with longer periods of muscle work at greater than 50% of initial force output, as compared with relatively shorter stimulus off times.

These findings support the results of the limited literature available on the topic. Benton et al reported a decrease in the dorsiflexion force output of a patient with hemiplegia to less than 50% of its initial value within 2 minutes of stimulation at a 1:1 duty-cycle ratio and within 7 minutes of stimulation at a 1:3 duty-cycle ratio, whereas at a 1:5 duty-cycle ratio torque was maintained at >80% of its initial value for the duration of the 8-minute recording session.[13] Kots demonstrated that duty-cycle ratios of 1:1, 1:2, 1:3, 1:4, and 1:5 were progressively less fatiguing over a 10-minute stimulation session.[14]

In this study, the duty-cycle ratio of 1:5 was associated most often with stimulation sessions of >30 minutes, the 1:3 ratio with 11- to 20-minute sessions, and the 1:1 ratio with 1- to 10-minute sessions of >50% of initial force output. Of the three duty-cycle ratios tested, therefore, the 1:5 ratio appears to be most suitable for initial use in a program of prolonged

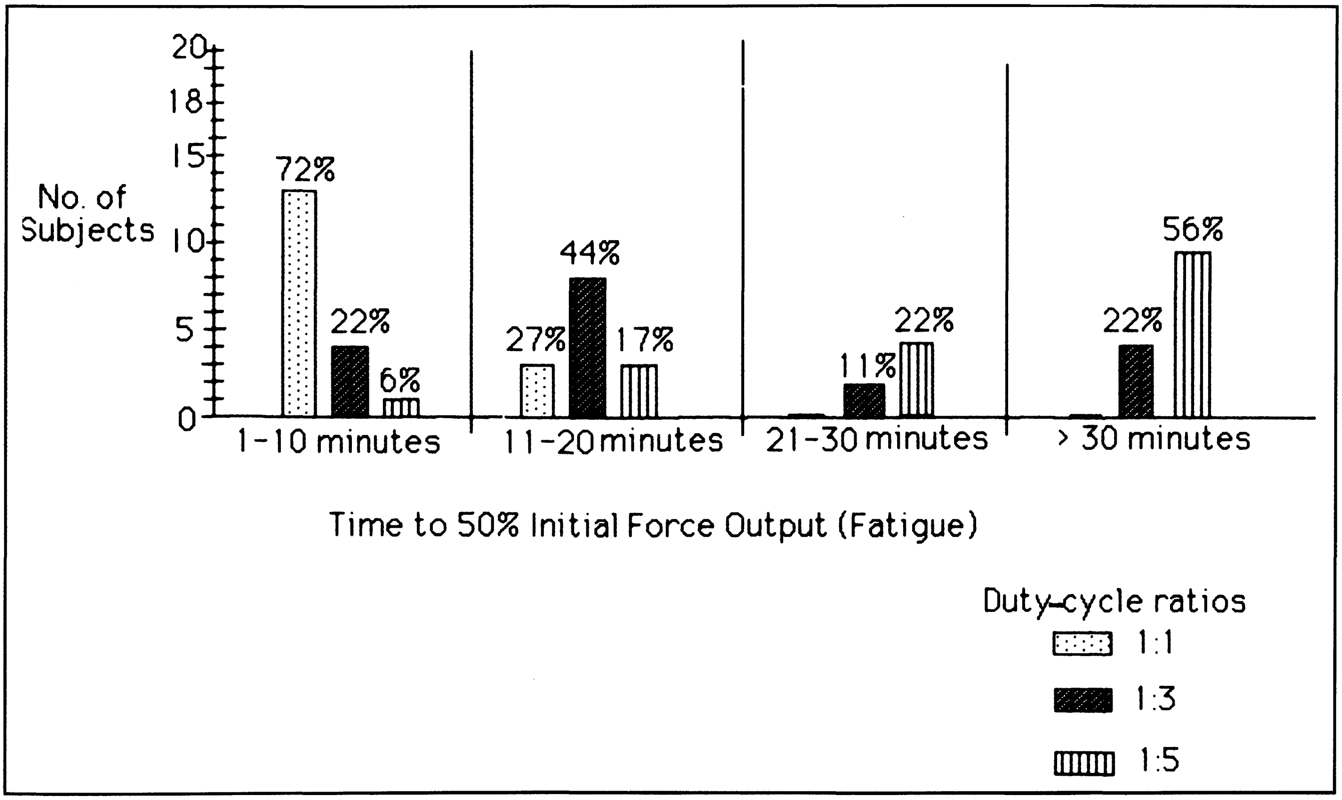

Fig. 4. Duration of stimulation session necessary to induce fatigue at three different duty-cycle ratios. (Recorded times were rounded off to the nearest minute.)

(20–30 minutes) electrical stimulation of the wrist muscles of patients with hemiparesis, if the goal is to maintain torque throughout the treatment session.

Although the 1:5 ratio was the most effective of the duty cycle ratios tested in maintaining force output over a period of time, the question remains as to whether an even longer stimulus off time with respect to stimulus on time (eg, a duty-cycle ratio of 1:6 or 1:10) might yield better results. Although longer rest periods between stimulated contractions will produce slower onsets of muscle fatigue, the greater the stimulus off time, the fewer will be the number of contractions elicited within a given treatment period. At some point, it becomes necessary to evaluate the functional significance of fewer muscle contractions at a higher percentage of initial force output versus a greater number of contractions at a lower force output. Some compromise between quality and quantity may be required to create the optimum treatment protocol. The strong performance of the 1:5 duty-cycle ratio in this study indicates that it is an appropriate choice for the stimulation characteristic, duty cycle, if the treatment goal is to maintain torque at ≥ 50% of its initial value.

Another question that must be addressed is whether the results of this study may be generalized to other patients with hemiparesis and to healthy individuals. Patients with hemiparesis are very heterogeneous in terms of the site and severity of their lesions and the resultant degree of motor and sensory involvement.[21] In any given patient, different muscle groups may be affected to very different degrees. Generalizations about their probable responses to various treatments, therefore, are very difficult to make.

Patients with hemiparesis and various degrees of wrist extensor muscle function participated in this study. The testing protocol involved repeated measures, with the patients functioning as their own basis for comparison. Although some patients generally showed greater muscle endurance than others, 13 of the 18 patients had a better result with a 1:5 stimulation ratio than with either of the other ratios tested. These results are supported by the work of Benton et al on the dorsiflexor muscles of a single patient with hemiplegia.[13] This trend suggests the need to investigate the influence of this duty-cycle ratio on other muscle groups in patients with hemiparesis. The results of this study possibly will be more applicable for programs of stimulation to smaller, more superficial muscle groups such as the wrist extensors than they will be for programs of stimulation to larger, deeper muscle groups such as the quadriceps femoris. In general, postural muscles also may prove to be less vulnerable to fatigue than phasic muscles such as the wrist extensors.

Although the patients in this study had intact peripheral nervous systems, further study will be required before the results of this investigation can be applied to nonhemiparetic individuals who may require FES to the wrist extensor muscles for other (eg, orthopedic) problems. Abnormalities in muscle tone alone might account for the effects on neuromuscular fatigue and force of muscle contractions seen in the patients in this study. The previously mentioned work by Kots[14] on duty cycle and fatigue in wrestlers, however, does support the general hypothesis of this study.

CONCLUSION

Few guidelines currently exist for the setting of FES characteristics for clinical treatment programs. Clinicians and researchers daily make decisions in this area based only on common sense and on previous experience, which often is limited. The stimulus characteristics selected, therefore, often

are vastly different from program to program and from study to study, despite similar therapeutic or investigative goals.

Obviously, all stimulation characteristics are not equally effective in producing desired physiological results. Without an appropriate choice of stimulation variables, an accurate evaluation of the effectiveness of FES for any purpose in any individual or group is impossible.

Analysis of the results of this study revealed that the duty-cycle ratio is an important factor affecting the onset of muscle fatigue. Furthermore, a duty-cycle ratio of at least 1:5 should be used initially to enhance the effects of FES to the wrist extensor muscles of patients with hemiparesis. Further clarification of optimal settings for this and other stimulation characteristics is needed. Within the limitations of this investigation, the hypothesis was accepted that the smaller the stimulus off time with respect to stimulus on time, the greater will be the muscle fatigue over time.

Acknowledgments. I express my appreciation to Bruce Sutton, President, Stress and Test Corporation, for his assistance in the planning and adaptation of the instrumentation used in this study. I also thank James T. Demopoulos, MD, former Medical Director; Robert Habasevich, Director of Physical Therapy; and the physical therapy department staff of Moss Rehabilitation Hospital, Philadelphia, PA, and William E. Staas, MD, President and Medical Director; Gail D. Miller, Director of Physical Therapy; and the physical therapy department of Magee Memorial Rehabilitation Hospital, Philadelphia, PA, for their cooperation in providing access to patients for the study.

REFERENCES

1. Godfrey CM, Jayawardena H, Quance TA, et al: Comparison of electrostimulation and isometric exercise in strengthening the quadriceps muscle. Physiotherapy Canada 31:365–367, 1979
2. Laughman RK, Youdas JW, Garrett TR, et al: Strength changes in the normal quadriceps femoris muscle as a result of electrical stimulation. Phys Ther 63:494–499, 1983
3. Eriksson E, Haggmark T: Comparison of isometric muscle training in the recovery after major knee ligament surgery. Am J Sports Med 17:169–171, 1979
4. Gould N, Donnermeyer D, Pope M, et al: Transcutaneous muscle stimulation as a method to retard disuse atrophy. Clin Orthop 164:215–220, 1982
5. Baker LL, Yeh C, Wilson D, et al: Electrical stimulation of wrist and fingers for hemiplegic patients. Phys Ther 59:1495–1499, 1979
6. Munsat TL, McNeal DR, Waters RL: Preliminary observations on prolonged stimulation of peripheral nerve in man: Recent advances in myology. In: Proceedings of the Third International Congress on Muscle Disuse. Newcastle-upon-Tyne, England, 1974, pp 42–50
7. Bowman BR, Baker LL, Waters RL: Positional feedback and electrical stimulation: An automated treatment for the hemiplegic wrist. Arch Phys Med Rehabil 60:497–502, 1979
8. Vodovnik L, Rebersek A: Improvements in voluntary control of paretic muscles due to electrical stimulation. In Fields WS, Leavitte LA (eds): Neural Organization and Its Relevance to Prosthetics. New York, NY, Intercontinental Medical Book Corp, 1973, pp 101–116
9. Lindstrom B, Korsanbengtsen K, Jonsson O, et al: Electrically induced short-lasting tetanus of the calf muscles for prevention of deep-vein thrombosis. Br J Surg 69:203–206, 1982
10. Dooley DM, Kasprak M: Modification of blood flow to the extremities by electrical stimulation of the nervous system. South Med J 69:1309–1311, 1976
11. Eckerson LF, Axelgaard J: Lateral electrical surface stimulation as an alternative to bracing in the treatment of idiopathic scoliosis: Treatment protocol and patient acceptance. Phys Ther 64:483–490, 1984
12. Waters RL, McNeal D, Perry J: Experimental correction of footdrop by electrical stimulation of the peroneal nerve. J Bone Joint Surg [Am] 57:1047–1054, 1979
13. Benton LA, Baker LL, Bowman BR, et al: Functional Electrical Stimulation: A Practical Clinical Guide, rev ed. Downey, CA, Professional Staff Association of Rancho Los Amigos Hospital, 1981, pp 11–54, 127
14. Babkin D, Timtsenko N (trs): Notes from Y. M. Kots', PhD, (USSR) lectures and laboratory periods. Canadian-Soviet exchange symposium on electrostimulation of skeletal muscles. Concordia University, Montreal, Quebec, Canada, December 6–15, 1977
15. Currier DP, Mann R: Muscular strength development by electrical stimulation in healthy individuals. Phys Ther 63:915–921, 1983
16. Axelgaard J, Brown JC: Transcutaneous electrical muscle stimulation for the treatment of progressive scoliosis and kyphosis. In: Proceedings of the Seventh International Symposium on Scoliosis and Kyphosis. Lubljand, Yugoslavia, May 6–9, 1981, pp 3–7
17. Currier DP, Lehman J, Lightfoot P: Electrical stimulation in exercise of the quadriceps femoris muscle. Phys Ther 59:1508–1512, 1979
18. Vodovnik L, Bowman BR, Hufford P: Effects of electrical stimulation on spinal spasticity. Scand J Rehabil Med 16:29–34, 1984
19. Merletti R, Zelaschi F, Latella D, et al: A control study of muscle force recovery in hemiparetic patients during treatment with functional electrical stimulation. Scand J Rehabil Med 10:147–154, 1978
20. Siegel S: Nonparametric Statistics for the Behavioral Sciences. New York, NY, McGraw-Hill Book Co, 1956
21. Barnett HJM: Cerebral ischemia and infarction. In Wyngaarden JB, Smith LH (eds): Cecil Textbook of Medicine, ed 16. Philadelphia, PA, W B Saunders Co, 1982, vol 2, pp 2056–2058