Muscle Fatigue: Clinical Implications for Fatigue Assessment and Neuromuscular Electrical Stimulation
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Muscle fatigue can be defined as a decrease in the force-generating ability of a muscle that resulted from recent activity. Recent studies of muscle fatigue are reviewed that are relevant to two areas of interest to physical therapists: clinical assessment of muscle fatigue and neuromuscular electrical stimulation. Volitional and electrical tests have been used to quantify muscle fatigue. Several variations on each type of test are discussed, as are the possible sites in which fatigue might occur. The rate of fatigue during the therapeutic application of electrical stimulation of skeletal muscle is much greater than that seen during volitional contractions. Factors contributing to this phenomenon are examined. The unique requirements affecting how stimulus variables can be manipulated to minimize muscle fatigue in three specific therapeutic uses of neuromuscular electrical stimulation are addressed. [Binder-Macleod SA, Snyder-Mackler L. Muscle fatigue: clinical implications for fatigue assessment and neuromuscular electrical stimulation. Phys Ther. 1993;73:902-910.]

**Key Words:** Electrotherapy, electrical stimulation; Fatigue; Musculoskeletal system; Skeletal muscle

Fatigue has been described as a "failure to maintain the required or expected force" from a muscle following repeated activity of the muscle.1 This is a functional definition of fatigue; fatigue may result from a myriad of biological and motivational factors. Failure anywhere along the pathway involved in muscle activity, from the central nervous system (CNS) to crossbridge cycling within the muscle, could result in a loss of force output from a muscle.2,3 Recent studies4-6 have shown that in well-motivated subjects, however, decreased CNS drive does not appear to be a major factor in the reduced force output from skeletal muscle during prolonged activity. Force decline during maximal voluntary efforts in healthy subjects does not appear to be due to effects on transmission of the nerve action potential to the muscle, or to the transmission of information across the neuromuscular junction.4,7 Thus, in healthy subjects, aside from consideration of motivational and psychological factors, the major source of fatigue appears to be within the muscle fiber itself. Muscle fatigue can be defined as a decrease in the force-generating ability of a muscle resulting from recent activity.4,9 This definition means that muscle can be tested as an isolated entity if proper procedures are used and that contributions of motivation and CNS drive in modifying force output can be eliminated.

Mechanisms that occur at a number of sites have been implicated in causing muscle fatigue.2,3,10 These sites include conduction of the action potential along the muscle fiber membrane and into the transverse tubule system; release of Ca2+ into the myoplasm from the sarcoplasmic reticulum; the binding of Ca2+ to troponin C, which causes the exposure of the active sites on the actin molecule; interaction between myosin and actin during crossbridge cycling; and active re-uptake of Ca2+ from the myoplasm into the sarcoplasmic reticulum.5 It is beyond the scope of this review to detail the specific mechanisms that may be operating at each of these sites to produce fatigue, but other recent reviews are available.2,3,10,11
this article, we will review recent studies of muscle fatigue that are relevant to two areas of interest to physical therapists: clinical assessment of muscle fatigue and neuromuscular electrical stimulation (NMES).

**Clinical Assessment of Muscle Fatigue**

Volitionally and electrically elicited fatigue tests have been used to quantify muscle fatigue. Although all of the tests we discuss measure force or torque decrements, they may test different sites of fatigue. We will discuss several variations on each type of test and the possible sites at which fatigue may be occurring.

There are a plethora of electrophysiological and biochemical factors that affect a muscle's contractile ability. A number of sites may simultaneously contribute to the loss in force-generating ability of a muscle. During a particular activity, however, one site may be primarily responsible for the loss of force. If a muscle is stimulated with a tetanizing, high-frequency series of pulses, for example, the loss in force is primarily due to a reduction in muscle action potential amplitude. This type of fatigue is termed high-frequency fatigue, and one of its characteristics is the rapid rate of recovery of force production capability seen following a very brief rest. The amount of fatigue and the particular sites that are responsible for the fatigue are a function of the characteristics of both the muscle and the contraction being produced.

The responses of different muscle fiber types to prolonged activity are well documented. Type I fibers use oxidative processes as their primary metabolic mechanism, and they have a high capillary density and an enormous capacity to resist fatigue. Type IIb fibers use glycolytic processes as their primary metabolic mechanism, have a low capillary density, and are quickly fatigued. Type IIa fibers use both oxidative and glycolytic processes for metabolism, and their capillarization and fatigue responses are more like those of Type I fibers. Human muscle is heterogeneous, consisting of all three fiber types, and therefore has mixed biochemical responses under all contractile conditions. In contrast, individual motor units are homogeneous with respect to their fiber type composition. Individual motor units may be classified physiologically as slow-twitch fatigueresistant (S), fast-twitch fatigueresistant (FR), and fast-twitch fatiguable (FF), with each motor unit type composed of Type I, Type IIa, and Type IIb fibers, respectively (see article by Clamann in this issue for description of motor units).14,15

**Volitional Fatigue Tests**

Tests that use volitional contraction both to produce the fatigue and to measure the amount of fatigue have been described by Thorstensson and Karlsson. Subjects performed repeated maximal knee extension efforts at 180°/s, and the torque output for each contraction was recorded on an isokinetic dynamometer. The subjects performed either 50 or 100 contractions (0.5 second contraction; 0.7 second relaxation). The average peak torque for the last three contractions was divided by the average peak torque of the first three contractions and used as a fatigue index. Thorstensson has been criticized for using a relative fatigue index (making a ratio of final force to initial force) without correcting the torque values for the effect of gravity.17 For any relative fatigue index that involves the use of ratios, the smaller the measured torque relative to the torque produced by the weight of the extremity, the greater the error. Thus, with submaximal contractions or in the case of very weak muscle, the potential error introduced by failing to correct for the effect of gravity may be clinically significant. The use of a computer-controlled electromechanical dynamometer, which allows gravity correction to be performed automatically, can eliminate this problem. Thorstensson and Karlsson16 reported a coefficient of variation of 3.4% for this measure, but other more traditional measures of reliability have not been reported. Other researchers18 have used the test developed by Thorstensson as a measure of muscle fatigue.

A fatigue test described in the instructional manual for the Cybex II dynamometer* (Cybex test) has been widely used clinically. Subjects perform repetitive, maximal-effort, reciprocal, isokinetic contractions, and the number of contractions before the peak torque falls to 50% of the initial peak torque is used as the index. Reliability of Cybex test measurements in healthy subjects has been reported by Burdett and Van Swearingen19 as very good, as measured by an intraclass correlation coefficient of .84. All of the caveats regarding gravity correction mentioned previously are germane to this test as well. In addition, the use of reciprocal, maximal contractions has been criticized, although in practice there is evidence to support that reciprocal contractions can yield reliable measurements.20,21 The theoretical constructs for this and similar fatigue tests have not been developed, nor has experimental evidence shown that these tests predict functional performance (eg, ability to do recreational or vocational tasks).

Bigland-Ritchie et al3 have used a combined volitional and electrical fatigue test to assess the fatigue evoked by intermittent submaximal voluntary contractions of muscles with different relative fiber compositions. Subjects were asked to hold a targeted force level for 6 seconds (eg, 50% of maximal voluntary contraction [MVC]), then to rest for 4 seconds. The subjects repeated this 10-second cycle until they could no longer attain the targeted force level. Periodically during the test, the subjects performed an MVC, or an eight-pulse, 50-Hz electrical train was delivered to the resting muscle. The response to

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*Cybex, Div of Lumex Inc, 2100 Smithtown Ave, Ronkonkoma, NY 11779.
the 50-Hz train and the MVC values were highly correlated, indicating that the electrical and volitional components were measuring the same physiological phenomena. Dolmage and Cafarelli\(^2\) varied the fatigue protocol slightly, but used the same assessment tool and had similar results with respect to the electrical and volitional torque values.

A potential disadvantage of tests that use volitional contraction forces to assess the amount of fatigue is that it may not be possible to isolate the site of fatigue. If subjects are not well motivated, or have a disorder that affects central drive (eg, following a cerebrovascular accident), measured losses in force generation may not be reflecting muscle fatigue. Clinically, however, volitional effort may be most representative of the phenomenon we are trying to evaluate.

**Electrically Elicited Fatigue Tests**

Investigators\(^23,24\) have attempted to use electrically elicited fatigue tests as a clinical tool for assessing muscle performance. A particular test that we have used to assess muscle performance in patients following surgical repair of their anterior cruciate ligaments (ACLs)\(^23\) is a modification of a fatigue test originally described by Burke and colleagues\(^14\) to categorize cat single motor units. The test consists of stimulating the muscle once per second with 330-millisecond, 40-pulse-per-second (pps) groups of electrical pulses (pulse trains) and measuring the percentage of decline in force production. Burke et al suggested repeating these pulse trains for 120 seconds. We have modified the procedure slightly, and repeat these pulse trains for 180 seconds. We have shown this procedure to yield extremely reliable measurements.\(^25\)

McDonnell and colleagues\(^26\) have attempted to design a clinically applicable fatigue test using a commercially available stimulator. They used a 2,500-Hz carrier frequency, bursted 50 times per second, with a 7-second on time (including a 2-second ramp) and a 2-second off time. They delivered this current for 50 contractions, using a stimulus intensity sufficient to generate 60% of the force developed in an MVC. Their experiments were performed on the quadriceps femoris muscle, and the decrement in torque was recorded. The reliability of measurements obtained with this test was demonstrated in healthy human subjects. Although both of these tests appear to produce reliable measurements, the validity of the measurements has never been demonstrated.

**Validity (Interpretation) of Fatigue Tests**

The specific fatigue test used affects the amount and rate of fatigue and determines the specific mechanisms that are responsible for fatigue. Different tests may examine different aspects of a muscle. Recently, for example, Barclay and Loiselle\(^26\) tested the effects of a hypocaloric diet in female Wistar rats and found that a fatigue protocol that required a high rate of energy supply, thereby forcing a dependence on glycolytic metabolic pathways, produced considerably more fatigue in the hypocaloric rats than in matched controls. In contrast, a fatigue test that required much lower rates of energy supply, where all needs could be met entirely by oxidative metabolic processes, showed no effect. The high-energy protocol consisted of 100-pps, 4-second trains repeated once every 12 seconds (1:3 duty cycle). The low-energy-demand protocol consisted of 30-pps, 0.25-second trains repeated once every 5 seconds (1:20 duty cycle). This study showed that the stimulation paradigm can affect which specific biochemical mechanisms are responsible for muscle fatigue.

Thorstensson and Karlsson\(^16\) found that performance on his test correlated highly with a percentage of fast-twitch motor units within the muscle. The Cybex test has demonstrated relatively rapid rates of fatigue.\(^26,27\) Both of these fatigue tests appear to stress glycolytic pathways to a greater degree than oxidative pathways.

Bigland-Ritchie et al\(^8\) found that the quadriceps femoris muscles could no longer reach the 50% of MVC target within 5 minutes, whereas the soleus muscle was able to reach the target for greater than 30 minutes. Although both muscles fatigued, the quadriceps femoris muscle fatigued sooner. This finding may indicate that the test stressed glycolytic pathways to a greater degree than oxidative pathways. It appears, from the on and off times that we\(^23\) and McDonnell and colleagues\(^24\) used, that both of these tests also primarily test glycolytic pathways. Often, however, either of the volitional or electrical tests described are used to evaluate response to treatments such as bicycle training. We would expect this type of training to affect primarily the oxidative pathways. In a recent set of studies, Sinacore and colleagues (David R Sinacore, PhD, PT; personal communication) had subjects train using a strenuous cycling program. Performance of the quadriceps femoris muscles on the electrical fatigue test described by McDonnell and colleagues and the volitional fatigue test described by Thorstensson and Karlsson\(^16\) did not change after training. Thus, the use of either of these tests may not detect the physiological changes that we commonly associate with improved "endurance." Clinicians must be cautious when attempting to use the results of any fatigue test to make inferences about the functional capacity of a muscle without considering the aspects of muscle performance that the test is measuring.

We have begun to address the issue of validity of our fatigue test in testing patient populations.\(^28\) Patients who have undergone ACL reconstruction have weak quadriceps femoris muscles. It is generally assumed, though never documented, that these muscles are also less endurant then the contralateral uninvolved quadriceps femoris muscles. We recently reported the results of our fatigue test protocol from these patients and showed, to our initial surprise, that the involved muscles had greater fatigue resistance than the uninvolved contralateral muscles (Fig. 1). To explain these
findings, we suggested a selective Type IIb fiber atrophy of the involved muscles resulting in a greater percentage of the force being generated by fibers with a higher oxidative capacity. Our fatigue test, by stressing the glycolytic pathway, may have shown less fatigue because the glycolytic fibers were contributing a smaller percentage of the initial force in the involved extremities. These findings have led us to question the notion that the involved muscles are truly less endurance. The clinical observation that these muscles appear to fatigue more quickly may be due solely to muscle weakness, and atrophy of high force-producing glycolytic fibers means that a greater amount of force is generated by the endurant oxidative fibers. Because the involved muscles are weaker, however, they must be contracting at a higher percentage of their capacity to perform typical functional tasks, such as ambulation. Thus, even if both muscles fatigue (have force decrements) at the same rate, the weaker muscles will be able to maintain functional force levels for shorter periods of time and will appear to fatigue sooner.

We have recently completed work that demonstrates that as the weak quadriceps femoris muscle becomes stronger, its fatigueability increases and the muscle performance on strength and fatigue tests approaches that of the healthy quadriceps femoris muscle (unpublished observations) (Fig. 1). As the Type IIb fibers increase in size, they contribute a greater percentage of overall force in the muscle, and the muscle will show greater fatigueability when a fatigue test that stresses glycolytic systems is used.

**Clinical Electrical Stimulation**

Electrical stimulation of skeletal muscle is used for a variety of purposes in physical therapy. Applications range from producing a limited number of near-maximal muscle contractions of the quadriceps femoris muscle for muscle strengthening following knee surgery to repetitive activation of lower-extremity muscles to allow individuals with spinal cord injuries to ambulate.

The rate of fatigue during electrical stimulation of skeletal muscle is much greater than that seen during volitional contractions. Several factors contribute to this phenomenon. First, the order of motor unit recruitment during volitional contractions allows the most fatigueresistant motor units to be selectively recruited during low-force contractions. In contrast, during electrically elicited contractions, many of the rapidly fatigueresistant motor units are recruited even at low stimulation intensities. These differences in recruitment order probably contribute to the greater fatigue seen at low force levels with electrical stimulation. Second, the frequencies needed to produce near-maximum force levels appear to be much lower during volitional contractions than during electrically elicited contractions. The recruitment of motor units asynchronously during volitional contractions and synchronously during electrical stimulation also probably contributes to the differences in the frequencies needed to produce maximum force. Higher frequencies result in a much more rapid fatigue.

Third, when volitional effort is tested, the CNS can vary the use of motor units and modulate their discharge rates to help to maintain a targeted level of force. During electrically elicited contractions, neither of these mechanisms is used. Fatigue is a major clinical concern during virtually all applications of electrical stimulation of skeletal muscle and must be considered when selecting stimulation settings.

**Effects of Selected Stimulation Settings**

When electrical stimulation is used clinically, brief electrical pulses are grouped together in trains to produce tetanic contractions. These trains of...
Figure 2. Peak forces (expressed as percentage of maximal voluntary contraction [%MVC]) produced by the quadriceps femoris muscle of a healthy subject produced in response to 1.5-second trains of pulses using frequencies ranging from 1 to 100 pulses per second (pps). Two stimulation intensities were used. The lower trace (lower intensity) used a stimulation intensity that produced approximately 20% of the subject's maximal voluntary contraction when the muscle was stimulated with the 100-pps train. The upper trace (higher intensity) used an intensity that produced approximately 50% of the subject's maximal voluntary contraction with the 100-pps train. This figure shows two possible combinations for producing a contraction that is approximately 15% of the subject's maximal voluntary contraction at the lower intensity, a 36-pps train would be needed; at the higher intensity, a 12-pps train could be used.

pulses are maintained for as long as the contraction is needed. The trains are turned off between contractions to allow the muscle to rest. The stimulation variables that are thought to have the greatest impact on muscle fatigue are the stimulation intensity, which includes the pulse amplitude and duration; the train frequency; and the on and off times of the train.36,59

There are primarily two ways that muscle force can be regulated during electrical stimulation. The intensity can be varied, to recruit more or fewer motor units, and the train frequency can be modulated.36 Increasing the strength of contraction by either mechanism will place greater metabolic demands on the whole muscle, will produce greater circulatory occlusion, and will result in an increase in the rate of fatigue. For all submaximal forces, a variety of stimulation intensities and frequencies can be used to produce a targeted level of force (Fig. 2). The specific combination of intensity and frequency used, however, will affect the fatigue observed.

**Stimulation Intensity**

The stimulation intensity will affect the number of motor units recruited. As previously noted, during volitional contractions we know that motor units are generally recruited in an orderly manner, with the least fatiguable motor units recruited first and the more fatiguable motor units recruited with stronger contractions.32 In contrast, during electrically elicited contractions, there is likely a different pattern of recruitment. Previous investigators, using direct motor nerve stimulation40 and transcutaneous neuromuscular stimulation,41,42 have suggested a recruitment order that was the reverse of that seen during volitional contractions: Most fatiguable motor units recruited at low contractile levels, and least fatiguable motor units recruited at high contractile levels. A "reversal" in recruitment order would result in a higher percentage of fatiguable motor units in the activated motor unit pool at low stimulation intensities and a higher percentage of fatigue-resistant motor units in the motor unit pool at higher stimulation intensities. Recent studies by Krafft et al44 and others (personal observations) that have examined the recruitment order during transcutaneous neuromuscular stimulation, however, have failed to support this notion of an obligatory "reversal" of recruitment. Rather, they have suggested a more random recruitment of muscle fiber types over a range of contraction intensities.

**Stimulation Frequency**

In human skeletal muscles, if the stimulation intensity is kept constant, increasing the stimulation frequency will increase the rate of muscle fatigue.39,45–47 Marsden and colleagues48 have suggested that the rate of fatigue is a function of the number of pulses delivered to a muscle. More recent findings have shown that the relationship is not that simple and that the rate of muscle fatigue depends not only on the number of pulses delivered to a muscle, but also on the frequency46,47 and pattern of stimulation.46,49,50 Garland et al47 were the first to show that, though fatigue occurred sooner with a higher-frequency train, less fatigue per pulse was observed when a muscle was stimulated with higher-frequency trains than with lower-frequency trains. Nevertheless, from a functional perspective, higher stimulation frequencies will produce fatigue sooner than lower stimulation frequencies. One problem with extrapolating the results of many of these studies to the clinic is that if we hold the stimulation intensity constant and vary the stimulation frequency, we are also varying the force that the muscle produces. Thus, it is difficult to sepa-
rate out the effects of stimulation frequency from the effects of force output on muscle fatigue.

Recently, Binder-Macleod and colleagues39 (unpublished observations) attempted to identify the specific contributions that stimulation intensity and frequency make to muscle fatigue. The quadriceps femoris muscles of 29 nondisabled subjects were transcutaneously stimulated with 330-millisecond trains having a frequency of 20, 40, or 60 pps. The intensity was set so that for each frequency, subjects would produce peak isometric contractions that were either 20% or 50% of their maximal voluntary isometric contraction. Thus, a total of six combinations were tested. To produce fatigue, these 330-millisecond trains were repeated once per second for 180 seconds. Only one intensity and frequency combination was tested during a session. The results showed that either increasing the stimulation intensity while keeping the frequency constant or increasing the stimulation frequency while keeping the initial force level constant significantly increased the amount of fatigue (Fig. 3).

These results suggest, therefore, that to minimize fatigue during repetitive activation, such as is used with functional electrical stimulation (FES), we want to use the lowest frequency (and highest intensity) that produces targeted forces. Patient comfort and the force output needed set limits on the range of frequencies and intensities that can be used.

Effects of On and Off Times of Trains

Though low-frequency trains targeted to produce relatively low force levels will minimize fatigue, we often need to stimulate muscles with relatively high frequencies and intensities to produce near-maximal tetanic contractions. The rate of muscle fatigue is markedly dependent on the duration of the rest period between contractions51,52; the shorter the rest, the greater the rate of fatigue. It has been noted that rest periods of approximately 60 seconds' duration are needed between contractions of approximately 10 seconds' duration to prevent muscle fatigue during muscle strengthening with electrical stimulation.

One of the few studies that has systematically investigated the effects of the rest time, was the recent study by Barclay52 (also see Packman-Braun53). Mouse extensor digitorum muscles were studied using a train frequency of 200 pps and a train duration of 0.9 second. For all rest times of 30 seconds or less, the shorter the rest period, the greater the decrease in force. In contrast, rest times equal to or greater than 60 seconds did not produce significant declines in force. These results are consistent with the rest times of approximately 60 seconds used during muscle strengthening.

Clinical Relevance: Effects of Muscle Fatigue on Stimulation Characteristics

Neuromuscular electrical stimulation is commonly used as a substitute for a brace or orthosis (FES) to assist with range-of-motion (ROM) exercises and to augment muscle strength. Each of these therapeutic uses has unique requirements that affect how the therapist can manipulate intensity, frequency, and on and off times of the stimulus to minimize muscle fatigue.

With FES (eg, use of electrical stimulation to produce purposeful muscle activity), on and off times cannot be manipulated to minimize fatigue. The train duration must be linked to the need for functional activity. For example, when a stimulator is used to activate the ankle dorsiflexors during walking, the stimulator needs to be on during the swing phase of the gait cycle. The electrically elicited force must always be at least equal to the force level necessary to perform the functional task. Again, using the dorsiflexion assist example, the electrically elicited muscle contraction must always be sufficient to dorsiflex the foot to at least the neutral position against gravity. If the force level is not maintained, the functional activity cannot be carried out and the treatment fails.

Because the on and off times of the train cannot be controlled, we must use the stimulation frequency and intensity that minimize fatigue. The

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**Figure 3.** Average forces (expressed as percentage of initial force) being produced by the quadriceps femoris muscles of a group of healthy subjects at the end of a 3-minute fatigue test that used 330-millisecond trains of pulses repeated once every second.
Figure 4. Response from a typical subject at the beginning (top panel) and at the end (lower panel) of a 3-minute fatigue test. The legend notes the frequency of the 330-millisecond trains that were repeated once every second. The variable-frequency train (VFT) starts at a high frequency, 80 pulses per second (pps) for the first three pulses, lowers its frequency to 40 pps for the next pair of pulses, and then drops to 20 pps for the remainder of the train. The VFT shows less fatigue than any of the other trains that used a constant frequency.46

Stimulation frequency should be low: at or just above the level that is required for tetanic fusion to minimize fatigue. In addition, recent studies46,49,50 have shown that brief trains that begin with a high frequency and then drop to a lower frequency can markedly reduce the amount of muscle fatigue produced compared with trains that use only low or high frequencies (Fig. 4). Thus, not only the frequency or number of pulses can affect fatigue, but also the pattern of stimulation. We believe that this high-to low-frequency train, which is known as a variable-frequency train, has significant potential as a means of enhancing force output from skeletal muscle during short-duration trains of pulses, as is used during FES.

When electrical stimulation is used to assist with ROM exercises, the on and off times of the train can be varied, but not to an unlimited degree. The electrically elicited force must be sufficient to take the joint through its entire ROM; if the force level is not maintained, the treatment fails.

As with FES, stimulation frequency should be low, at or just above that required for tetany to minimize the effect of fatigue. On and off times need to be balanced with the number of cycles of ROM the therapist has determined is required and the amount of time available for treatment. Packman-Braun,51 in her study of the effect of stimulus on and off times on fatigue in wrist extensor muscles of patients with hemiplegia, found that virtually all of the patients were able to maintain more than 50% of initial force output for longer than 10 minutes with a 5-second-on/25-second-off pattern (two contractions per minute). Eighty percent of the patients were able to maintain this force level for longer than 20 minutes with the 5:25 ratio. Eighty percent of the patients were able to maintain more than 50% of initial force output for longer than 10 minutes with a 5-second-on/15-second-off pattern (three contractions per minute). This study suggests that on and off times can be manipulated to alter the effects of muscle fatigue on treatment.

Evidence suggests that high contractile forces are necessary to augment muscle strength (eg, have a training effect).53,54 High forces can only be achieved using high-frequency and high-intensity stimuli. This type of contraction is very fatiguing and would likely result in a rapid loss of contractile force if the off times were short. Fortunately, off times can be varied almost indefinitely. The point at which the force-frequency curve levels off for the quadriceps femoris muscle in young healthy subjects is between 65 and 85 pps (Fig. 2).56 To produce the strongest electrically elicited contraction for a given stimulus intensity, we believe that a stimulus frequency in this range should be used. Studies of patients after ACL surgery26 and of healthy subjects53 have demonstrated large gains in quadriceps femoris muscle strength.
using 10-second on times and 2-minute off times for 10 to 15 contractions per session. Off times can thus be lengthened so the effects of the high frequency, intensity, and force can be minimized.

Conclusions

Muscle fatigue must be considered when planning a treatment program using NMES. The NMES characteristics can be varied to alter the fatigue response, but the choice of which characteristics to vary must be considered within the context of the treatment goals. A patient's inability to repeatedly perform functional tasks can result from a plethora of phenomena that may evaluate phenomena that might be lengthened so the effects of the high frequency, intensity, and force can be minimized.

References


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