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Differences in Torque Generation by Trial and Three Different Waveforms

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ABSTRACT: The purpose of this study was to determine if there was an increase in torque production between trials of maximally tolerated, electrically induced muscle contractions. Thirty-three "healthy," electrically naive subjects participated in two consecutive trials of maximally tolerated contractions. Eleven subjects were assigned to one of three waveform groups, consisting of medium frequency current, symmetrical biphasic current, or direct interferrential urrent. In the first trial, each subject received two maximally tolerated, 10-sec muscle contractions, with a 50-sec rest between contractions. After a 10-min rest period, the second trial was administered in the same fashion. Significantly greater torque ($F_{(1;30)}$ =19.31; p<01) was produced in the second trial when compared with the first. No statistical significance was found for differences in torque production between waveforms or for interaction effects. These results suggest that a learning effect may exist during treatment using maximally tolerated muscle contractions.

Key Words: Electrical Stimulation, Phase Charge, Learning Effect

INTRODUCTION

It has been documented that electrical stimulation used to produce involuntary isometric contractions can yield torques from 30% to 91% of maximal voluntary isometric torque (MVIT).[1,2] By generating a minimum of 30% to 50% of a subject's MVIT, electrical stimulation can promote significant strength gains.[3,4] In work that has yet to be reproduced, the Russian physiologist Yakov Kots[5] has claimed to have elicited involuntary isometric torque exceeding those elicited voluntarily. In his study, Kots reported strength gains of 30% in 4 weeks. With the knowledge that increased electrical stimulation intensities will yield increased involuntary torque production, researchers have attempted to increase subjects' tolerance to greater intensities of current.[6,7] Although it has not been documented, it is theorized that increased tolerance to electrical current will enhance strength gains.

Snyder-Mackler et al[8] compared the torque produced by three waveforms and found a significant difference in torque production among the three stimulators that were used. It was concluded, however, that torque generation is not dependent on waveform. Instead, they concluded that torque production was directly related to phase charge. Other work has been performed in an attempt to determine if pain modulation modalities would enable subjects to tolerate a greater amount of electrical stimulation and, consequently, allow for greater involuntary torque production.[6,7] In a study by Durst et al,[6] no effect was found in the torque produced by electrical stimulation following treatment with ice. Underwood et al[7] demonstrated that torque production was increased with application of conventional transcutaneous electrical nerve stimulation (TENS) prior to electrical stimulation. The results of that study appear to offer support to a theory proposed by Melzack and Wall[9] that stimulation of large diameter, afferent fibers will excite an interneuron pool that inhibits the transmission of noxious stimuli via the anterolateral system. Although the majority of researchers agree that adaptation to electrical stimulation occurs, not all find it to have the effect of increasing torque production. Currier and Mann[1] and Wong[10] felt that subject accommodation to electrical stimulation resulted in decreased torque production.

It has not been documented whether repeated trials of electrical stimulation of intensities greater than motor threshold alter torque production between trials. The purpose of this study was to determine if application of a maximally tolerated stimulus of three waveforms commonly used in the clinic creates an effect resulting in greater torque production with repeated trials. We hypothesized that there would be a significant increase in torque between trials.

METHODS

Subjects

This study was approved by the Brooke Army Medical Center Clinical Investigations Committee and Institutional Review Board. Thirty-three active-duty military males, ages 18 to 30 years, participated in the study. Subjects had no history of right knee injury or hypertension, and had a body fat percentage less than 30%. None had previously been exposed to electrical stimulation. All subjects signed volun-

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teer affidavit agreements and informed consent forms.

Equipment

The Electrostim 180-2™*, VMS™†, and Omnistim 3020™†† electrical stimulators were used. The Electrostim 180-2 uses a 2500-Hz carrier wave to deliver 10-msec bursts of current at an effective frequency of 50 bursts per second. The Chattanooga VMS provides a symmetrical biphasic square wave, with a phase duration of 200 µsec, at 50 pps. The Omnistim 3020 delivers a direct interferential current, full field, at 2500 Hz, with phase duration of 200 µsec. The Kin-Com III™ isokinetic dynamometer and Kin-Com 4.0 software§ were used to record torque generated by voluntary and electrically produced muscle contractions.

Procedure

Subjects were positioned on the Kin-Com isokinetic dynamometer with the backrest reclined to 70 degrees and the right knee flexed to 60 degrees.[11] Subjects were stabilized in accordance with Kin-Com protocol, with the right knee axis of rotation in line with the axis of rotation of the dynamometer. The Kin-Com was calibrated before each data collection period.

Three MVIT measurements were obtained, with verbal encouragement, to be used for comparison with electrically induced contractions. The greatest torque value of the three contractions was used as MVIT. Subjects rested for 10 min before electrically stimulated trials were measured.

Subjects were assigned randomly, using a table of random numbers, to one of the three waveform conditions. To maintain a constant skin-electrode interface size, 7.6 cm x 12.7 cm, carbon-rubber electrodes were used with all three stimulators. A sponge of equal size and soaked with tap water was placed between the skin and the electrode. Electrodes were secured with elastic straps. Current from the Electrostim 180-2 and VMS was delivered via two electrodes, one over the femoral triangle, and the other over the distal quadriceps 1 inch proximal to the superior boarder of the patella.[12] The four electrodes from the Omnistim 3020 were positioned such that the geometric intersection of the two circuits was at the motor point of the quadriceps femoris. The motor point was identified as the site of visible contraction with the least amount of current.[4] Subjects could not view the electrical stimulator during the experiment.

After placement of the electrodes, the subject was instructed to allow the current to be increased to their pain tolerance, resulting in the subject's maximum tolerable muscle contraction (MTC). Subjects were instructed to relax prior to, and during, the stimulation. The only response requested of the subject was to indicate when pain tolerance was reached. Two trials consisting of two, 6-sec stimulations each were recorded. Each 6-sec stimulation was preceded by a 4-sec ramping of the current to the subject's pain tolerance. A 50-sec rest period followed the first stimulation, and there was a 10-min rest period between trials. The greater torque for each trial was recorded as the MTC generated for each of the two trials.

Data Analysis

The peak MTC for each waveform and each trial was expressed as a percentage of pretest MVIT. Descriptive statistics were calculated for all variables (Table 1). A two-way mixed ANOVA with repeated measures on one factor was conducted to determine whether statistically significant differences existed among the three waveforms (factor A), and between the two trials (factor B), the repeated factor, and the resultant interaction. The level of alpha for evaluation of significance was set at 0.05.

RESULTS

The mean %MVIT (MTC/MVIT) values by trial for each waveform are presented in Table 1. As shown in Figure 1, higher %MVIT measures are consistently associated with the second trial for all three stimulator types. The results of the ANOVA are presented in Table 2. Main effects were observed to be nonsignificant for waveform (factor A). The interaction (A * B) effects were also found to be nonsignificant. However, the trial's main effect (factor B) was found to be significant ($p \leq 0.01$). The power of the analyses was greater than 0.80 for each main effect and the interaction. These results indicated that subjects increased their %MVIT from the initial to the final trial.

DISCUSSION

The purpose of this study was to determine if there is an increase in torque production between trials of maximally tolerated, electrically induced muscle contractions. Also, our study was designed to determine if waveform is a significant variable in torque production. Statistically significant evidence was found in support of the former and not the latter. This indicates that a sensory adaptation to the electrical stimulation occurred between trials, with a resultant increase in torque produced.

The relationship between current delivered and force produced has been demonstrated previously.[9,16] This adaptation phenomenon may be due to the modulating influence of electricity on pain perception, thus decreasing apprehension of the subject during the subsequent trial. The gate control theory, as proposed by Melzack and Wall[11] indicates that large, myelinated, afferent fibers suppress pain transmission cells. Additionally, electrical stimulation between motor and pain threshold is believed to provide pain relief via endogenous opiates.[4]

Research by Durst et al[8] and Underwood et al[16] produced different results when applying well-accepted forms of pain-reducing modalities. Durst et al[8] noted that there was a decrease in torque produced with the application of ice between trials. They attributed this to decreased nerve conduction velocity and decreased elasticity of muscle fibers. Underwood et al[16] found that application of TENS significantly increased torque production between trials. They proposed that TENS causes an excitation of interneuron pools that increase tolerance to

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TABLE 1. Mean ± Standard Deviation of %MVIT for Trial and Stimulator (n = 11)

Stimulator	Trial 1	Trial 2
Electrostim 180-2	50.1 ± 19.1	56.3 ± 17.3
Chattanooga VMS	39.7 ± 21.5	52.1 ± 18.4
Omnistim 3020	53.5 ± 25.1	66.9 ± 20.6

TABLE 2. ANOVA Source Table

Source	SS	*df*	MS	*F*	*p*
Stimulator	2254	2	1127	1.56	NS
Error (S/A)	22298	30	743		
Trial	1881	1	1881	19.32	< 0.05
Stimulator x Trial	165	2	83	0.85	NS
Error (B x S/A)	2920	30	97		

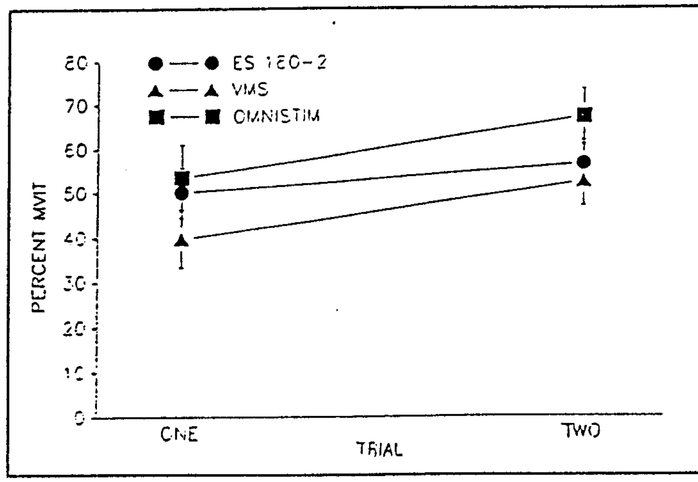

FIGURE 1. %MVIT (mean ± SE) by trial and stimulator.

the noxious properties of electrical stimulation. Our research could be explained by the activation of interneuron pools; however, our electrical stimulation parameters are outside the accepted parameters of conventional NS.

Another explanation for the increase in torque produced may be a learning effect. We define the learning effect as a perceptual or psychological adaptation to the current. Delitto and Rose[4] and Wong[17] noted that subjects were apprehensive to the high level of muscle contractions produced by electrical stimulation. This effect was observed more dramatically in subjects who were electrically naive. We suggest that clinicians observe the same trend in any type of application of electrical current. Wong[17] reported a low perceived level of discomfort on the second trial of maximally tolerated contractions. She felt that this was due to ramping the current only to the level of the initial stimulation on repeated trials. She explained that the method used allowed the subjects to feel "safe" on subsequent trials. The observed increase in torque production in our study may be explained by the subjects' expectations or perceptions prior to the first trial. In most cases, between stimulation trials, subjects expressed that the current was not painful during the first trial. They did, however, state that they expected the current to be painful. Most subjects described the sensation as "strange," but thought that they would be able to accept more current during the second trial. Wong[17] stated that this occurred during the data-gathering process in her study as well.

No significant difference in torque production was found among the three waveforms studied. The range of torque produced for all currents for this study was 39 %MVIT to 53 %MVIT for trial 1, and 52 %MVIT to 67 %MVIT for trial 2. These data also include five subjects from waveform 2 (VMS) who were able to tolerate the full output of the stimulator. If a greater range of current had been available, higher mean torque levels may have been achieved. The range of MVIT compares closely with work done previously by Snyder-Mackler et al[14] using similar waveforms. Surveying other similar studies finds the range to fall roughly between 50 %MVIT and 90 %MVIT[11], the range commonly accepted as necessary for a strengthening effect. In contrast to Snyder-Mackler et al,[14] the phase durations of each of the waveforms in this study were matched at 200 μs. This phase duration has been shown to be in the optimal range (20 μs to 200 μs) for motor stimulation of the quadriceps group.[15] The matched phase durations resulted in no significant difference among waveforms, which supports the conclusion of Snyder-Mackler et al[14] that differences among the torque generating capabilities of a waveform are directly proportional to phase charge. In terms of clinical practice, different waveforms do not seem to produce consistently different torques.[1,5,14] Therefore, the ability of a stimulator to produce a greater amplitude is the definitive factor in stimulators designed for torque production.

Cox[2] reported that the 50-sec rest interval between contractions seemed to be optimal for muscle recovery. Lower intervals were associated with greater torque decrements, suggesting incomplete muscle recovery. Intervals greater than 50 sec had a similar torque decrement over repeated trials. Selkowitz[12] also stated that a longer rest interval between contractions was required to allow greater recovery, and used 120 sec as his recovery period. Based upon these works, we chose 50 sec between contractions within trials, and 10 min between trials to ensure complete recovery. The results of our study support that complete recovery did occur in the 10-min period. Further research could be directed to determine whether a sensory or psychological adaptation occurs over a period of 24 to 48 hours. This may be more clinically relevant than the 10-min rest period chosen in this study, as this is the usual time between treatments.

The results of this study may be helpful when physical therapists choose electrical stimulators for their practice. These findings would appear to confirm the results of Snyder-Mackler,[8] and suggest that the intensity-generating capability of the electrical stimulator is the key feature for achieving increased muscle strength, regardless of waveform.

Further research needs to be conducted to explain the accommodation and learning effects described in this study. Accommodation could be measured by current accepted as opposed to torque produced. Also, the similar results noted between work performed by Underwood et al[16] and this study need to be more carefully investigated. Is there a relationship between the effect of TENS and repeated trials with any type of waveform? Possibly there is no such effect, just a learning effect by electrically naive subjects.

CONCLUSION

The results of this study indicate that a short, intense electrical stimulation above motor threshold of the quadriceps femoris muscle group results in increased torque production between successive trials. Also, based upon our findings, we agree with Snyder-Mackler[8] that the torque-producing capability of a particular waveform seems to be proportional to phase charge.

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