Effect of Electrical Stimulation Protocols of Low Frequency Pulsed Current on Muscle Torque

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ABSTRACT

Background: *Electrical stimulation is a promising tool in the rehabilitation of individuals with limited ability to activate their skeletal muscles. Therefore investigating the parameters that could maximize torque output is a key element to the application of electrical stimulation. The Purpose of the study was to compare the effect of different electrical stimulation protocols on the peak isokinetic quadriceps muscle torque for healthy subjects.* ***Materials and Methods:*** *Forty healthy male subjects participated in this study with a mean age of 19.8±0.74 years. They were assigned randomly into two equal groups. Group (I) received pulse duration modulation protocol and group (II) received pulse duration and frequency modulation protocol. Isokinetic concentric peak torque of the non dominant quadriceps muscle was evaluated before and after training. Training was administered at low velocity (60^0/sec) in the functional range from 90 degree knee flexion up to 0 extensions while electrical stimulation was administered for 10 minutes, three times a week, in alternative days, for four weeks.* ***Results:*** *There was a significant increase in the peak torque between groups (I) and (II) as P value was 0.0001. Peak torque increased post training from156.82±35.0 to 166.64±34.92 for group (I) and from 158.69 ±27.46 to 210.33±22.18 for group (II).* ***Conclusion:*** *Group (II) produced better improvement in peak torque. Electrical stimulation protocol that progressively increased pulse duration first to the maximum level followed by progressively increased frequency produced augmentation of peak torque of the quadriceps muscle than the protocol that progressively increased pulse duration only while keeping constant frequency.*

Key words: *Electrical stimulation protocols –low frequency current- torque.*

INTRODUCTION

Electrical stimulation (ES) is a promising tool in the rehabilitation of individuals with limited ability to activate their skeletal muscles. It is used extensively throughout the world to augment muscle strength[24].

During voluntary contraction the central nervous system (CNS) controls skeletal muscle force output by varying both the activation frequency (firing rate or rate coding) and the number of activated motor units (recruitment)[5]. So that muscle force can be controlled by varying the ES frequency and intensity[6].

The stimulation intensity can be modulated by adjusting either the current amplitude or pulse duration (PD) of the stimulus. The PD of the stimulus is easier to control and provide more consistent force response from the muscle compared to stimulation amplitude[15].

The pulse parameters that most commonly adjusted to maximize torque output include the PD and frequency of the pulses. These parameters influence the recruitment of the nerves which can be recruited by many different combinations of these two parameters[1,22].

Few studies have systematically varied the stimulation parameters that would allow maximum force generation during each training session. Increasing PD from 150 to 450 microseconds (µs) has recently been shown to increase motor unit recruitment and evoked more torque[13]. While other investigators concluded that the combination stimulation protocol that progressively increasing the PD to the maximum levels first then the frequency is the best strategy to improve muscle performance[6].

Within the available literature, there was no recent prospective study has systematically investigated the accumulative training effects of ES following repeated sessions over weeks using different stimulation protocols of frequency and pulse duration modulations. So, the purpose of the study was to investigate the effect different electrical stimulation protocols on the peak isokinetic quadriceps muscle torque. This could provide physical therapists with effective protocols concerning augmentation of muscle strength and could be used for musculoskeletal and neuromuscular disorders.

SUBJECTS, MATERIALS AND METHODS

Forty healthy male volunteers were recruited for the study from the Faculty of Physical Therapy, Cairo University students and employees. Their age were ranged from (18 – 30) years old. Subjects were randomly assigned into two equal groups. Each group was consisted of twenty male subjects. Subjects were excluded if they had any contraindication for electrical stimulation or received any beverages containing caffeine regularly or missed two sessions.

Instrumentations

1- Bio-Trac Plus: It is the device that was used to deliver neuromuscular stimulation. It is a small hand-held battery powered (9 volts) unit for single or dual-channels operation with independent output control, with asymmetric biphasic pulse, frequency ranges from (2 to 100) Hz, pulse duration ranges from (50 to 450) µsec, treatment time ranges from (0 to 30) minutes and amplitude ranges from (0 to 80) mA. The device manufactured by EMS Physio. Ltd. England. The portable stimulators have been used in many studies, researchers found that portable stimulators produced comparable levels of peak torque at comparable levels of discomfort to those produced by clinical stimulators[18,19,20].

2- Biodex system III isokinetic dynamometer: It is the device that was used to measure the isokinetic concentric peak torque of non dominant quadriceps femoris (QF) muscle before and after training. The system has visual and auditory biofeedback. It is provided with computer system (IBM compatible) that collects, displays, stores the isokinetic test data and controls the movements of dynamometer. It has been widely used in research, clinical setting and rehabilitation to objectively assess factors of muscle performance. The validity and reliability of the Biodex isokinetic dynamometer has been investigated under static and dynamic conditions with satisfactory results[8].

Procedures

All evaluating and training procedures were done at Faculty of Physical Therapy, Cairo University. After signing a written consent form, all subjects underwent the same evaluation procedures included:

- Subjects' ages were recorded and their height and weight were measured.
- The non dominant lower extremity was determined by asking the subject to kick a ball in front of him. The limb that was used to kick the ball is considered to be the dominant one while the other limb is considered to be the non dominant one.

Isokinetic concentric peak torque of the non dominant QF muscle was assessed before and after training at low velocity (60^0/sec) in the functional range from 90 degree knee flexion up to 0 extensions as it more representatives for dynamic muscle performance[7,9]. Each subject was allowed to do first unrecorded three light trial repetitions of knee extension and flexion before the test as warm up and to familiarize with the system then the subject did maximum five repetitions of knee extension with angular velocity 60°/sec[11]. The subject asked to sit on the dynamometer's chair with the tested knee at 90^o Flexion; the back support was adjusted to allow hip angle 110^o to the horizontal. This test position had been shown to be reliable for yielding maximal knee torques[(15)]. The resistance pad placed at the lower leg, two centimeters above the medial malleolus. A thigh strap, waist strap, and 2 chest straps were then secured to stabilize the subject in the dynamometer chair (figure 1 a). The dynamometer's axis of rotation was aligned with the lateral femoral epicondyle, and the knee was extended from 90 degrees to 0 degrees to ensure that the axis of rotation of the knee is aligned with the axis of rotation of the dynamometer. The knee was then positioned in 90 degrees of flexion. The speed of the dynamometer was set at 60^o/sec. Gravity correction was performed throughout the test. The subjects was instructed to hold the sides of the padded seat for added stabilization and maximally contract their non dominant QF muscle following the command pull (figure 1 b). The highest torque reading of the five trials was accepted as the peak torque[11].

(a) (b)

Fig. (1): Starting position of the test, with knee flexed 90 (a). Final position of the test, with full extension of the knee (b).

Training procedures

Subjects in group I received constant frequency (50 Hz) and progressive increases in pulse duration (150 µsec for the first week, 250 µsec for the second week, 350 µsec for the third week and 450 µsec for the fourth week) (Pulse-duration-modulation protocol)[13]. While subjects in group II received PD progressively increased every two sessions (150 µsec, 300 µsec and 450 µsec) till the end of the sixth session (at frequency 30 Hz) then progressive increase in frequency every two sessions (40 Hz, 50 Hz and 60 Hz) for the next six sessions (at PD 450 µsec) till the end of the last session (Pulse duration and frequency modulation protocol)[6]. For both groups duty cycle was set at 4 seconds on and 16 seconds off (duty cycle of 20%) and the intensity of the stimulator will be adjusted to the current that could be maximally tolerated by each subject for 10 minutes. Electrical stimulation was administered three times a week, in alternative days, for four weeks[17,25].

Electrical stimulation was administered to the non dominant QF muscle. The proximal electrode was placed over the upper thigh covering the proximal portion of rectus femoris and vastus lateralis muscles (15 cm distal to anterior superior iliac spine). The distal electrode was placed over the lower aspect of the thigh covering distal bulk of vastus medialis (figure 2)[16]. Prior to application of electrodes the skin over the electrode placement site was cleaned with alcohol swabs and to ensure consistent electrode placement for the next sessions a clear plastic sheets was placed over the subject's thigh or using permanent marker according to subject's preference[19]. The intensity was increased gradually until the subject could not tolerate further increase in intensity after a short periods habituation to the stimulus was occurred the subject was asked again (can you tolerate further increase in intensity?) at this level maximum tolerable intensity was recorded for each subject[17].

Fig. (2): Position of the subject and electrodes placement during application of electrical stimulation.

Statistical Analysis

Descriptive statistics including the mean and standard deviation was used to describe ages, weights and heights of participants. Student t test was used was used to determine significant differences in peak torques between both groups and to compare between pre and post test values of the peak torque within each group. The P-value < 0.05 was taken as significant.

RESULTS

Demographic characteristics of both groups presented in (table 1). There were no significant differences between both groups regarding age, weight and height (P>0.05).

Table (1): Demographic data of the subjects in both groups (I and II).

General Characteristics	Group (I)		Group (II)		Comparison	
	Mean	±SD	Mean	±SD	P-value	S
Age (year)	19.75	±0.63	19.9	±0.85	0.8	NS
Weight (Kg)	75.85	±10.34	77.3	±8.87	0.78	NS
Height (cm)	177.25	±6.23	175.8	±5.09	0.68	NS

*SD: standard deviation P: probability S: significant, NS: non-significant.

The results revealed that there was a significant increase in the peak torque for both groups as P value was (0.001). The mean values of peak torque increased post training from 156.82 ±35.0 to 166.64±34.92 for group I and from158.69±27.46 to 210.33±22.18 for group II as shown in table (2) and figure (3).

Table (2): Comparisons between mean values of peak torque Pre and Post training for both groups.

Variable	Group	Pre training		Post training		t-Value	P- Value
		Mean	SD	Mean	SD		
Peak torque	I	156.82	±35.0	166.64	±34.92	8.99	0.0001*
	II	158.69	±27.46	210.33	±22.18	23.37	0.0001*

* Significance at P<0.05 SD= standard deviation

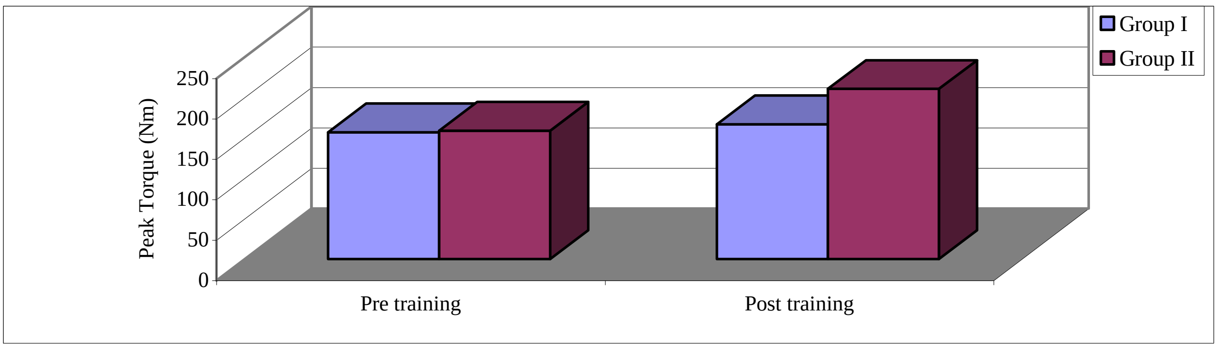

Fig. (3): Mean values of peak torque pre and post training for both groups.

Table (3): Percentage of improvement in the mean values of the peak torque.

	Group I	Group II
Percentage of improvement	6.26%	32.54%

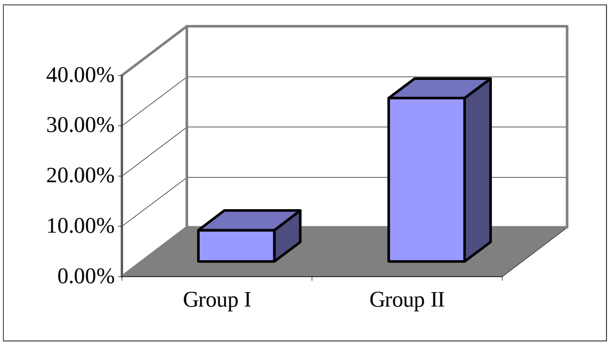

Fig. (4): Percentage of improvement in peak torque post training.

DISSCUSION

The purpose of this study was to investigate the effect of different electrical stimulation protocols on the peak isokinetic quadriceps muscle torque. This helped set a protocol for electrical stimulation that can be followed by physical therapists.

The principal finding of this study support that there were significant differences between the effects of the different ES protocols used in this study in the magnitude of the peak isokinetic quadriceps muscle torque. The combination stimulation protocol that progressively increased PD first to the maximum level followed by progressively increased frequency produced better improvement in the values of peak torque than the protocol that progressively increased PD only while keeping constant frequency.

These findings were in agreement with (Chou et al., 2008)[6] who suggested that the combination stimulation protocol that progressively increasing the PD then the frequency is the best strategy to improve muscle performance[6].

Based on the literatures, during voluntary contraction the CNS controls skeletal muscle force output by varying both the activation frequency (firing rate of activated motor unit or rate coding) and the number of activated motor units (recruitment). When the recruitment is completed at sub-maximal force levels, higher forces are achieved by using progressively higher activation rates of previously recruited motor units[23]. So that muscle force can be controlled by varying the ES frequency and intensity[6].

When low frequency pulsed current applied, the nerve fiber firing frequency will be equal the pulse frequency provided that the pulse intensity is sufficiently above threshold[26]. The stimulation intensity can be modulated by adjusting either the current amplitude or PD of the stimulus which is easier to control and provide more consistent force response from the muscle compared to stimulation amplitude[15]. The possible physiological mechanisms that could contribute to the findings of the current study include:

1- Force generation by each muscle fiber:

During the pulse duration modulation protocol, the frequency was maintained at 50 Hz throughout the protocol and the PD was modulated from (150 to 450 microseconds). Thus, a smaller fraction of the motor unit pool was recruited initially. Then, the PD was progressively increased to recruit more motor units. Motor units that were recruited earlier in the protocol continued to be activated throughout the protocol. Thus, motor units that were recruited early were activated for a longer period of time compared with the motor units that were recruited later in the protocol[21].

In contrast, during the combined PD and frequency modulation protocol, increased PD to 450 microseconds just after the end of the first week of training with ES leads to increase the activated area of the stimulated muscle and recruited more motor units[12]. Increased recruitment of motor units allowed sharing of force generation among a greater number of muscle fibers throughout the protocol which resulting in lower adenosine triphosphate (ATP) consumption per active muscle fiber by actin-myosin ATPase[21]. Therefore, the PD and frequency modulation protocol produced less fatigue in the recruited motor unit population and consequently improving muscle performance[6].

2- The number of stimulation pulses:

It also may have contributed to the large difference between the PD modulation and combined PD and frequency modulation protocols. During the PD modulation protocol, when all of the motor units were always activated at a high frequency of 50 Hz, a greater number of stimulation pulses were delivered to the muscle compared with during the PD and frequency modulation protocol, in which stimulation frequency was progressively increased from (30 to 60 Hz). The calcium ATPase and sodium-potassium ATPase reactions in response to each action potential contribute to ATP utilization during muscle force generation[14].

Because relatively fewer pulses were delivered during the PD and frequency modulation protocol compared with the PD modulation protocol, less ATP was utilized by the calcium ATPase and sodium-potassium ATPase during the frequency modulation protocol[10].

Muscle fatigue is related to metabolic demand. Higher stimulation frequencies contribute to more rapid muscle fatigue. Thus, the PD and frequency modulation protocol might be less fatiguing than the PD modulation protocol because it delivers fewer pulses to the muscles[2]. The PD and frequency modulation protocol appeared to be less fatiguing due to less metabolic demand per recruited muscle fiber by greater motor unit recruitment and by delivering fewer stimulation pulses, which resulted in better muscle performance than the PD modulation protocol at the end of training with ES[6].

3- The available range for frequency modulation

It can also be used to explain the differences in performance. There is a direct relationship between stimulation frequency and muscle force production, with near-maximal forces produced at approximately 60 Hz[3]. A 30 Hz frequency was the best starting stimulation frequency for quadriceps femoris muscle activation because it can prevent low frequency fatigue and retained a large capacity to increase force during frequency modulation[6].

Conclusion

Electrical stimulation protocol that progressively increased PD to the maximum level followed by progressively increased frequency produced augmentation in peak torque of the quadriceps muscle than the protocol that progressively increased PD only while keeping constant frequency. ES protocol that used combined modulation of both PD and frequency is an effective stimulation strategy for augmentation of muscle strength and could be used for musculoskeletal and neuromuscular disorders.

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الملخص العربي

تأثير بروتوكولات التنبيه الكهربائي للتيار المتقطع منخفض التردد على عزم العضلة

التنبيه الكهربائي وسيلة واعدة في تأهيل العضلات ويستخدم بصورة شائعة في العالم لزيادة قوة العضلات. ولذلك فإن دراسة معايير التنبيه الكهربائي التي نستطيع من خلالها زيادة قوة العضلات مطلوبة لتطبيق التنبيه الكهربائي . وتهدف هذه الدراسة إلى: مقارنة تأثير البروتوكولات المختلفة للتنبيه الكهربائي على أقصى عزم للعضلة الرباعية والتي يمكن من خلالها وضع أفضل بروتوكول للتنبيه الكهربائي يمكن إتباعه بواسطة أخصائي العلاج الطبيعي. ولقد أجريت هذه الدراسة على: أربعين شخص من الأصحاء من الذكور متوسط أعمارهم 19.8±0.74 وتم تقسيمهم عشوائيا إلى مجموعتين متساويتين. المجموعة الأولى (بروتوكول النبضة الزمنية المتغير)، المجموعة الثانية (بروتوكول النبضة الزمنية والتردد المتغير). ولقد تم التنبيه الكهربائي لمدة عشر دقائق، ثلاث مرات أسبوعيا لمدة أربع أسابيع. وقد تم تقييم أقصى عزم للعضلة الرباعية قبل بدء التدريب وبعد انتهاء الأربع أسابيع فترة التدريب. وقد أظهرت النتائج: أنه هناك زيادة مؤثرة في العزم الأقصى للعضلة الرباعية بعد استخدام بروتوكول النبضة الزمنية والتردد المتغير بالمقارنة بالبروتوكول المغير للنبضة الزمنية. ويستخلص من البحث الآتي: أن بروتوكول التنبيه الكهربائي الذي يبدأ بالزيادة التدريجية للنبضة الزمنية إلى الحد الأقصى ثم يتبعها بالزيادة التدريجية للتردد نتج عنه أداء أفضل في العزم الأقصى للعضلة الرباعية من البروتوكول الذي يزيد تدريجياً النبضات الزمنية مع ثبوت التردد.