Efficacy of Transcutaneous Neuromuscular Electrical Stimulation Amplitude on Muscle Torque and Soreness

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ABSTRACT

Background: *Neuromuscular electrical stimulation is widely used by physical therapists to improve muscle performance, retarding muscle wasting following muscle denervation or immobilization and optimizing recovery of muscle strength during rehabilitation. Although many attempts were done, optimal stimulation amplitude has not been determined yet.* ***Purpose:*** *This study was conducted to determine the optimal amplitude of neuromuscular electrical stimulation that could be used to increase the torque of the quadriceps muscle.* ***Subjects:*** *Thirty healthy male and female physical therapy students with mean age 21.2 ± 3.7 years, weight 75.6 ± 8.4 Kg and height 174.3 ± 6.2 cm were assigned randomly into three equal groups.* ***Assessment****: the peak torque of quadricepsfemoris was measured before treatment and after 6 weeks of treatment using Biodex III isokinetic dynamometer. Muscle soreness was evaluated post treatment using visual analogue scale.* ***Methods:*** *Neuromuscular electrical stimulation was administered three times a week for 6 weeks at amplitude 18 % of maximum tolerated intensity (MTI) for group I, 69 % of MTI for group II and 91 % of MTI for group III.* ***Results:*** *The results revealed that the amplitudes of neuromuscular electrical stimulation produced significant increase in the quadriceps muscle torque in all groups were 26.95 %, 16.87 % and 15.79 % respectively. There was no significance difference among the three amplitudes for muscle torque and soreness..* ***Discussion and conclusion:*** *The finding revealed that neuromuscular electrical stimulation could improve the strength of normal innervated muscles. This improvement was due to more firing of motor neuron with small dose of electrical stimulation. The current study concluded that when the torque values was expressed as a percentage of maximum tolerated intensity (MTI) , it was found that NMES could produce about 26.95 %, 16,87 % and 15.79 % in group I,II and III respectively and there were no significant differences among the three amplitudes in causing muscle soreness.*
Key words: *Electrical stimulation, Amplitudes, Muscle torque and soreness.*

INTRODUCTION

Electrical stimulation (ES) is an effective technique in augmenting torque of healthy muscles and for assisting the recovery of muscles function after certain orthopedic injuries[11,15]. Electrical stimulation programs designed to augment muscles torque are characterized by specific parameters including: current wave form, intensity of stimulation, frequency, pulses, number of sessions per week, number of contractions per session and total number of sessions.

Although electrical stimulation program characteristics varied among studies, the reported results were similar. However no study has explored the optimization of electrical stimulation program[17].

Neuromuscular electrical stimulation (NMES) is the application of electrical current to elicit muscle contraction. The use of NMES for orthopedic and neuromuscular rehabilitation has grown significantly[6].

On the other hand, neuromuscular electrical stimulation is used by physical therapist to improve muscle performance. However muscle torque and fatigue of electrically induced contractions depend on the wave form used to stimulate the contraction, with monophasic and biphasic wave forms having an advantage over the polyphysic wave forms[1].

In addition, neuromuscular electrical stimulation became clinically established in post traumatic disorders. On the other hand NMES result in increased muscle strength, muscle fiber hypertrophy and increased muscle cross sectional diameter when used over a period of several weeks[14].

Torques produced by biphasic wave forms was always greater (by 20-25%) when compared with monophasic wave forms. Therefore when monophonic wave forms were used, reversing polarity generally caused an increase in torques by 20%, whereas polarity had no significant effect when using biphasic wave forms[18].

Furthermore, the use of electrical stimulation for muscle strength in research & clinical practice increased popularly. Training isometrically with electrical stimulation was reported to increase isometric quadriceps femoris muscle strength in healthy subjects[13].

Unfortunately few studies have systematically varied the stimulation parameters such as wave forms, pulse duration and frequency that would allow maximum force generation during each training session[17].

On the contrary, some studies found no increase in muscle strength following NMES; this was attributed to the low force output during the NMES as a result of the sensory discomfort and muscle soreness experienced by the subjects[3].

Several studies investigated the frequency, wave form of electrical stimulation and their effects on increasing the strength of skeletal muscle[18]. Few researches have studied the effect of stimulus amplitude as a parameter of electrical stimulation on the strength of skeletal muscles and the most comfortable amplitude is not determined yet[4] .

Furthermore, this study might share in giving information about the most comfortable stimulus amplitude to increase torque of skeletal muscles with less muscle sorness that could help the physical therapist and physicians in sport medicine and physical therapy field in planning an advanced program of strengthing exercise.

Therefore the purpose of the current study was to investigate the effect of different amplitudes of NMES (18 %, 69 % and 91 % of MTI) on muscle torque, and muscle soreness of quadriceps muscle.

SUBJECTS, MATERIAL AND METHODS

Thirty normal volunteers recruited from the Faculty of Physical Therapy students and employees participated in the present study. Their ages ranged from 18 to 30 years old. The study was conducted at Faculty of Physical Therapy- Cairo University. The subjects (30 subjects) were randomly assigned into three equal groups. Each group consisted of 10 subjects. Electrical stimulation was administered three times a week, in alternative days, for six weeks. The design of the current study was pre-test, post-test "3×2" design (3 means of three different amplitude "independent variable" and two means of two dependent variable, muscle torque and soreness). The current study excluded subjects whom recent participated in an exercise program to increase strength; subjects had medical conditions in which NMES training was contraindicated and each subject who missed two successive electrical stimulation sessions. The stimulation intensities were arranged as following:

For **Group I:** The stimulation intensity was 18% of maximum tolerated intensity (MTI) to produce isometric contraction of quadriceps femoris (QF) muscle, for **Group II:** The stimulation intensity was 69% of MTI to produce isometric contraction of quadriceps femoris muscle and for **Group III:** The stimulation intensity was 91% of MTI to produce isometric contraction of quadriceps femoris muscle.

Instrumentation

A- Assessment instrumentation and tools

a) Biodex system

Biodex system, three isokinetic dynamometer was used to measure the torque of MVIC of nondominant quadriceps muscle. However this system was chosen because it has the ability to measure and perform isokinetic concentric, eccentric, isometric movements and provided with computer system (IBM compatible) that collects, displays, stores the isokinetic test data and control the movements of dynamometer.

b) Visual analogue scale

Visual analogue scale (VAS) was used to indicate the intensity of pain due to muscle soreness. The VAS consisted of a 10 cm horizontal line, the ends of which defined the minimum (no muscle soreness) and maximum (extreme muscle soreness). Each subject placed mark on the line to indicate the intensity of muscle soreness[7].

B- Treatment instrumentation

Sonopuls 992 device was used to deliver NMES with rectangular biphasic symmetric current. The frequency was 50 Hz and duty cycle 10 – 50 sec, pulse frequency options on the stimulator was ranged from 1 to 200 Hz. The pulse duration ranged from 50 to 400µs. and the interval times from 2 to 120 sec. The device was recalibrated before starting the study.

Procedures

A) Evaluative procedure

* Muscle Torque assessment

Each subject was fully acquainted with details of the procedures, which was undertaken through thirty minutes of demonstration session. Subjects' ages were recorded; their heights and weights were measured. Unrecorded trial was allowed for every subject. Each subject was allowed 5 minutes of warming up on a stationary bicycle before the evaluation. The dominant QF muscle was determined through specific questionnaire[7]. Quadriceps muscle peak torque was measured via MVIC by using Biodex system three isokinetic dynamometer. Each subject was asked to sit on the Biodex chair with knees off at the edge, adjusting the back support to allow hip angle 120° to the horizontal and the knee positioned at 60 ° flexion from full extension. Each subject was stabilized in the test position by straps around the trunk, waist and thigh. The inferior portion of the shin pad was adjusted two inches above the medical malleolus of tested limb. The fulcrum of the lever's arm was aligned with the most inferior aspect of the lateral epicondyle of the femur of the tested limb. The speed of the dynamomter was set at 0 % (isometric contraction). Each subject was asked to perform three consecutive MVIC trials of nondomenant QF and maintain MVIC for three seconds and finally having fifty seven seconds of rest between trials. During all contractions, each subject had to watch the pointer of the torque dynamometer and was encourage verbally to exceed his previous highest torque value. The greatest torque reading of the three attempts was accepted MVIC following the protocol of Soo and his coworkers[16]. The peak isometric torque was recorded before ES sessions and after the six weeks of ES.

*** Muscle soreness assessment**

The VAS was explained to patients, and each subject was asked to put mark on one of the scale numbers distance from zero to ten and expressed as pain intensity. The test was performed three consecutive times by the author and other therapist and the mean value was recorded.

B) Treatment procedure

Electrical stimulation with rectangular symmetrical biphasic current with one stimulation channel was used and electrodes were adjusted in which one electrode was placed 15 cm distal to the anterior superior iliac spine and the other electrode was placed over the distal bulk of vastus medialis muscle (just above upper border of the patella)[6]. Maximum tolerated intensity (MTI) was determined for each subject that produced peak torque of quadriceps muscle and then the percentage 18 %, 69 % and 91% were taken from peak torque. The parameters of the device was adjusted at frequency of 50 Hz. Pulse duration 400 micro seconds, interval times 50 seconds off. The intensity of ES was determined by mathematical calculation. Finally the relationship between MVIC and MTI was determined (if this ratio was 1:2; the intensity of ES for group I equal 36% of MVIC) at the last session of the 6th week and following ES immediately and after 15, 30, 45 minutes consequently, the mean of muscle soreness was recorded using VAS. ES was administered three times a week, in alternative days, for six weeks and the session was 30 min.

Data collection and statistical analysis

For testing the hypotheses that there was no significant difference between effects of different stimulus amplitudes of NEMS on muscle torque and soreness, the following statistical methods were used: Descriptive statistics, Inferential statistics (ANOVA), Paired student-t-test and Level of significance for all tests was set at < 0.05.

RESULTS

Thirty healthy male and female volunteers' subjects participated in the current study. Their ages ranged from 18-30 years with mean age 21.2 ± 3.7 years, their weights ranged from 58 - 90 kg with mean weight 75.6 ± 8.4Kg and their heights ranged from 160 - 185 cm with mean height 174.3 ± 6.2cm. The subjects were randomly divided into three equal groups. For group I the amplitude of ES was 18 % of MTI, for group II the amplitude of ES was 69 % of MTI and for group III the amplitude of ES was 91 % of MTI.

Effect of NMES on the QF muscle torque

I. for group I (amplitude 18 % of MTI)

The mean values of the QF isometric torque were increased from 187.72 ± 79.969 N.m before ES to 238.3 ± 63.587 N.m after the 6th week of ES as in table one and figure one.

Table(1): The effect of rectangular waveform on peak torque of quadriceps femoris measured in N.m in GI.

Condition	Before ES		After 6th weak		T Value	P
	Mean	SD	Mean	SD		
Group I	187.72	± 79.969	238.3	± 63.587	-4.295	<0.001

P: probability value (significant)   SD: Standard deviation

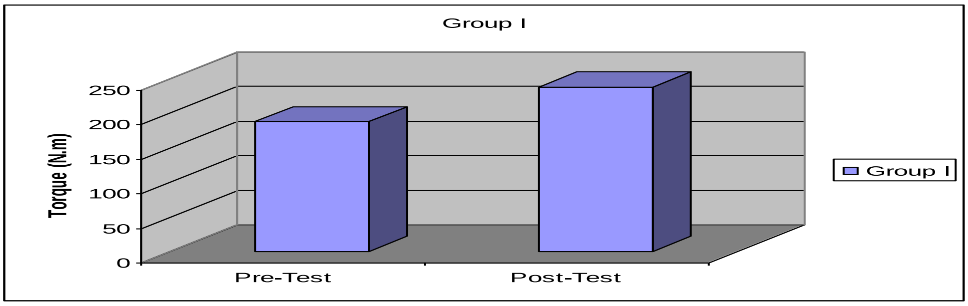

Fig. (1): The rectangular waveform on peak torque of quadriceps femoris in GI.

II. for group II (amplitude 69 % of MTI)

The mean values of the QF isometric torque were increased from 205.09 ± 63.353 N.m before ES to 239.68 ± 44.455 N.m after the 6th week of ES as in table two and figure two.

Table (2): The effect of rectangular waveform on peak torque of quadriceps femoris measured in N.m in G II.

Condition	Before ES		After 6th weak		t Value	P
	Mean	SD	Mean	SD		
Group II	205.09	± 63.353	239.68	± 44.455	-3.6	<0.000

P: probability value *(significant)* SD: Standard deviation

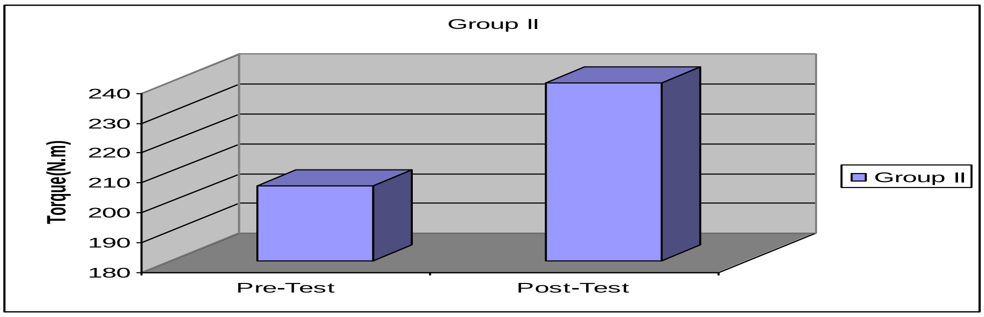

Fig. (2): The rectangular waveform on peak torque of quadriceps femoris in G II.

III. for group III (amplitude 91 % of MTI)

The mean values of the QF isometric torque were increased from 205.82 ± 86.387 N.m before ES to 239.99 ± 75.531 N.m after the 6th week of ES as in table three and figure three.

Table (3): The effect of rectangular waveform on peak torque of quadriceps femoris measured in N.m in G III.

Condition	Before ES		After 6th weak		T Value	P
	Mean	SD	Mean	SD		
Group III	205.82	± 86.387	239.99	± 75.531	-5.576	<0.000

P: probability value (significant) SD: Standard deviation

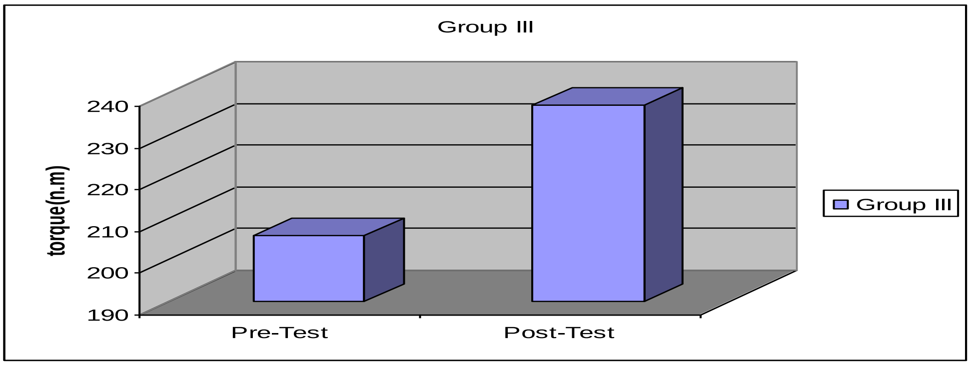

Fig. (3): The rectangular waveform on peak torque of quadriceps femoris in G III.

Results revealed that there was significant difference in peak torque between pre and post data of group I, group II and group III with more significance improvement in group I, II and III respectively.

IV-Visual analogue scale for pain rating in each group

The effect of different amplitudes of NMES on muscle soreness showed that, the mean values of muscle soreness were 1, 1.3 and 1.8 for group I, II and III respectively as in table 4 and 4 four. The results revealed no significant difference on muscle soreness among the three groups.

Table (4): Muscle soreness in three groups.

Variables	Mean	SD	P
Group I	1	±0.8	<0.222
Group II	1.3	±0.9	
Group III	1.8	±1.2	

P: probability value (non significant) SD: Standard deviation

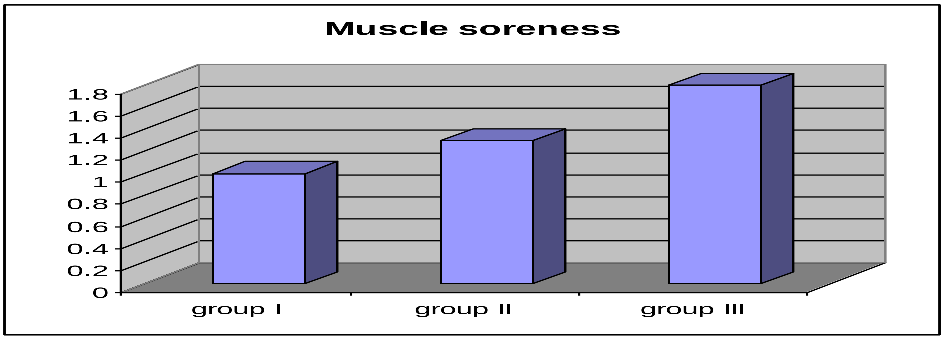

Fig. (4): Muscle soreness in three groups.

DISCUSSION

The objective of this study was to investigate the effectiveness of different amplitudes of neuromuscular electrical stimulation (symmetric biphasic rectangular current) on the quadriceps muscle peak torque and muscle soreness. In the current study the amplitudes used were 18, 69 and 91 % of MTI according to the protocol of Mark and Anthony[12]. However comparing the effect of different amplitudes among each others, no statistical significant differences were found among the three different amplitudes on the quadriceps muscle torque and soreness.

Furthermore**,** many investigators studied the ability of three different waveforms to generate isometric contractions of the quadriceps femoris muscles of individuals without known impairments, and compared muscle fatigue caused by repeated contractions induced by these same waveforms; In addition, they examined the effect of sex on muscle force production and fatigue induced by electrical stimulation[10]. Phase duration, frequency, and on-off ratios were kept identical for both stimulators. The results indicated that the monophasic and biphasic waveforms generated contractions with greater torque more than the polyphasic waveform. These two waveforms also were less fatiguing. The torques from the maximally tolerated electrically elicited contractions was greater for the male subjects than for the female subjects[10].

NMES was used for increasing QF muscle force in an elderly patient following a total knee arthroplasty. The results showed that the patient's isometric quadriceps femoris muscle force increased from 50% (involved/uninvolved) at three weeks after surgery to 86% at 8 weeks after surgery. The patient's final involved quadriceps femoris muscle force (10 weeks after surgery) was 93% of the initial uninvolved quadriceps femoris muscle force[11].

In addition, it was conducted a study with high intensity electrical stimulation of the quadriceps femoris and hamstring muscle group daily during a three-week period of lower extremity cast immobilization for an athlete who sustained Grade II medial collateral and anterior cruciate ligament sprains[2]. Thigh muscle hypertrophy of injured (stimulated) leg was suggested by an increase in girth measurement on the day of cast removal. Although muscle girth may not be related directly to muscle strength and power, the patient's ability to generate normal thigh muscle strength (measured by formal voluntary muscle testing) after three weeks of immobilization that some relationship exists between these factors and that electrical stimulation may had a major impact.

On the other hand, The efficacy of ES in improving QF strength in healthy subjects and compared interferential and low frequency current was investigated[5]. The results postulated that there was statistically significant increase in isokinetic strength in interferential group and low frequency current group with no significant differences between the stimulation groups. No significant change in strength occurred in the control group. Both interferential and low frequency currents can be used in increasing the strength with the parameters used in this study[5].

Furthermore, it was found that the greater the electrically elicited training contraction force, the greater the quadriceps femoris muscle recovery after anterior cruciate ligament reconstruction[16]. Training contraction intensity was linearly related to QF muscle strength only for training contraction intensities above 10 % of the uninvolved maximum voluntary contraction force.

On the contrary, the finding of current study was in disagreement with the work of many investigators, who was studied the effects of two pattern of high frequencies electrical stimulation on dynamic peak decline of human quadriceps muscle group. It was suggested that, the greater amounts of electrical stimulation produced lower current-induced contraction intensities with a greater amount of soreness[12].

In the present study, it was noticed that the improvement of muscle torque in group I was more than that of group II and III. This was attributed to small pulse duration which was increased to 400 microseconds or more to allow further motor unites to fire with less intensity which produced less muscle soreness.

In addition, the results of current study revealed that there were no significant differences among the effect of different amplitudes of three groups on the muscle soreness. This might attributed to long duration of intra-pulse interval of ES (50 sec off).

Conclusion

NEMS produced statistically significant changes in the isometric strength of the QF after ES treatment. When the torque values were expressed as a percentage of MTI, it was found that NMES could produce increase torque of QF at 18 %, 69 %, and 91 % of MTI respectively. Also it was concluded that there was no significant differences among the three amplitudes in augmenting of the QF muscle torque and causing muscle sorness.

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الملخص العربى

فاعلية شدة التنبيه العصبالعضلى عبر الجلد على عزوم و الام العضلة

يستخدم التنبيه العصبي العضلي علي نطاق واسع من قبل اخصائي العلاج الطبيعي لتحسين الاداء العضلي و تأخير ضمور العضلات الذى يعقب قطع العصب عن العضلة او التثبيت و ايضا لاستعادة القوة العضلية كاملة فى مجال التأهيل .الغرض من الدراسة الحالية هو تحديد الشدة المثالية للتنبيه الكهربى العضلى العصبى و التى من الممكن ان تستخدم لزيادة عزم عضلة الفخذ الرباعية . **الاشخاص :** شملت الدراسة على ثلاثين من الاناث و الذكور من طلبة وموظفين كلية العلاج الطبيعي كان متوسط أعمارهم 21.2±8.4 سنة ووزنهم 75.6±8.4 كجم والطول 174.3± 6.2سم . تم تقسيمهم عشوائيا الى ثلاث مجموعات متساوية . **التقييم :** تم تحديد قمة عزم العضلة الرباعية قبل بدء العلاج وبعد 6 أسابيع من العلاج باستخدام جهاز بيودكس ثلاثة بانقباض ثابت الشدة خلال المدى الحركي. أيضا تم تقييم الإجهاد العضلي بعد العلاج باستخدام المقياس المرئي الدال . **الطرق:** تم تطبيق التنبيه الكهرنى العضلى العصبى ثلاثة مرات اسبوعيا لمدة ستة اسابيع بشدة 18 % من اقصى قوة تحمل لشدة التيار و ذلك فى المجموعة الاولى و 69 % للمجموعة الثانية و 91 % للمجموعة الثالثة. **النتائج:** اشارت النتائج الى ان قوة التنبيه العضلى العصبى نتج عنها زيادة ذات دلالة احصائية فى عزوم العضلة الرباعية للركبة فى جميع المجموعات حيث بلغت 26.95 % ، 16.87 % و 15.79% فى المجموعات الثلاث على التوالى. و يعذى هذا التحسن لتهيج اشد فى الخلايا الحركية عند تطبيق جرعة اقل فى الشدة من التيار الكهربى. لا توجد فروق ذات دلالة احصائية بين المجموعات الثلاثة. **الخلاصة:** خلصت الدراسة ان التنبيه العضلى العصبى يمكن ان يحسن القوة العضلية للاشخاص الاصحاء و ان اقصى قوة تم الحصول عليها عن تطبيق شدة تيار 18 %، 69 %، 91% على التوالى من اقصى قوة تحمل لشدة التيار. و ايضأ لا توجد فروق ذات دلالة بين شدة التيارات الثلاثة فى زيادة قوة عزوم عضلة الفخذ الرباعية او التسبب فى اجهاد عضلى.

الكلمات الدالة: التبيه الكهربائى، الشدة، عزم العضلة، الام العضلة.