# EFFECTS OF SHORTWAVE DIATHERMY ON THE QUADRICEPS FEMORIS MUSCLE TORQUE DURING NEUROMUSCULAR ELECTRICAL STIMULATION AND VOLUNTARY CONTRACTION IN HEALTHY INDIVIDUALS

Fábio Chittero Boldrini[1]
Alexandre Dias Lopes[1]
Richard Eloin Liebano[1]

1. University of São Paulo (UNICID) – São Paulo, SP, Brazil.

Mailing address:
Richard Eloin Liebano
Departamento de Fisioterapia da Universidade Cidade de São Paulo (UNICID) - Rua Cesário Galeno, 448/475 - 03071-000 – São Paulo, SP, Brasil. liebano@gmail.com

## ABSTRACT

Introduction: The influence of the heat effects on muscle torque in males and females is still unknown, especially when associated with electrical stimulation. Objectives: To assess the effects of shortwave diathermy (SWD) on voluntary and electrically induced torque in healthy males and females, and to assess the discomfort produced by electrical stimulation. Methods: Twenty-six subjects participated in the study. Voluntary and electrically induced torque was assessed using an isokinetic dynamometer. The subjects were asked to attend 4 different sessions: measurement of maximal voluntary contraction (MVC); MVC after SWD; maximal electrically induced torque (MEIT); MEIT after SWD. Discomfort during MEIT was measured using a visual analogue scale. Results: MEIT was higher in males after SWD (p = 0.030). Females presented more discomfort during MEIT after SWD application when compared with male subjects (p = 0.044). Conclusion: SWD did not affect the MVC; however, there was increase in MEIT after SWD in males and discomfort increase in females.

Keywords: electrical stimulation, physical therapy modalities, muscle contraction.

## INTRODUCTION

Temperature increase in the muscle has presented effects in properties which contribute to the determination of muscle strength as blood flow, creatine phosphate, oxygen contribution, increase in velocity of nervous conduction, release of calcium and acetylcholine and metabolic activity[1-4], besides being able to provide boosting of the muscle function, such as muscle strength [3,5]. On the other hand, in the muscular system, temperature increase promotes decrease in the firing rate of the type II afferent and gamma efferent fibers[6] of the muscle spindle and increase in the firing rate of the Ib fibers of the Golgi tendon organ[7,8]. These alterations could lead to reduction in the capacity to generate muscler tension, contradicting the hypothesis suggested by the researchers previously mentioned.

The use of warm water jets in lower limbs of athletes from many sports such as swimming, basketball and gymnastics, promoted reduction of muscle strength, with recovery of contractile capacity after two hours from the application[3,9]. Cyclists submitted to immersion in hot water, presented immediate increase of 11% in peak torque[10]. The same way of heat application, on the triceps surae muscle this time, derived reports of dynamic performance improvement in cyclists and jumpers[11]. Results of increase in strength were also observed when shortwave diathermy was used on the quadriceps femoris muscle, and after two hours from the end of the application, muscular strength increased and remained above the level prior to the application[4].

Neuromuscular electrical stimulation (NMES) is commonly used in rehabilitation by physiotherapists with analgesic aim, for improvement of the muscular properties related to training such as production of torque of the quadriceps muscle, intramuscular blood flow and also as prevention measure[12-14]. The excito-motor current,

more popularly known for performance of NMES, is called Russian current, which is medium-frequency alternated current (2.500 Hz) modulated in bursts of 50 Hz with duty cycles of 50%. This current was initially described by Yakov Kots in the 70's decade, who reported strength gain in healthy muscles of elite athletes[15]. Currently, this current has been widely used in studies which evaluate maximal electrically-induced torque[16].

Physical agents such as heat an electrical stimulation have been massively used in the physiotherapeutic treatment for analgesic purposes, and benefits in the associated use of these devices have been observed when compared with the individual application of the modalities[6]. However, studies which present heat isolate effects concerning muscular strength are scarce and their results have been contradictory[3,4,9-11]. Moreover, no studies which associate neuromuscular electrical stimulation with thermal agents for torque production have been found. Studies about the influence of heat in the capacity of generating strength, as well as the association between heat and neuromuscular electrical stimulation, are extremely important, since they could contribute to the optimization of the strength gain programs, which are commonly used both in the clinical practice and in patients with hypotrophy due to extended immobilization time after surgical intervention.

The production of local heat in the muscle could present positive effects to NMES due to hemodynamic and neuromuscular alterations such as increase of blood flow, better oxygen contribution, ATP provision, optimization of nervous conduction and contractile components velocity, producing hence better conditions for use of the electrical stimulation, and consequently, improvement in muscular performance[8]. Furthermore, the analgesic effect produced by heat[17] could reduce the discomfort caused by the electrical

stimulation and make it better accepted by the patients and allowing the use of higher current intensities. Thus, the aims of this investigation were to analyze the short-wave diathermy effect in the torque of the quadriceps femoris muscle generated by voluntary contraction and in the electrically-induced torque in healthy individuals, and to evaluate the short-wave diathermy effects on the sensory discomfort caused by neuromuscular electrical stimulation during the production of electrically-induced torque.

## METHODS

### Participants

28 volunteers, out of which, 13 male and 15 female, aged between 18 and 25 years, BMI between 19 and 25 kg/m$^2$, who did not present history of surgical intervention, injuries or musculoskeletal and neuromuscular diseases of the dominant lower limb were selected for participation in this study. Two female volunteers who reported severe discomfort during the electrical current application were excluded from the study. Before the study performance, all volunteers received information about the procedures to be carried out, and signed a consent form accepting the participation. The present study was approved by the Ethics Committee in Research of the University of São Paulo under protocol n° 13.323.922.

### Instruments

Torque was determined with the use of an isokinetic dynamometer (Cybex® Norm 6000), previously calibrated. Application of deep heat was possible with the use of short wave device Diatermax 350P (KLD® – Biosistemas Equipamentos Eletrônicos Ltda.). Motor point of the rectus femoris and vastus medialis muscles was determined with the use of the device Nemesys941P (Quark® – Produtos Médicos), while for neuromuscular electrical stimulation, the Endophasys device was used (KLD® – Biosistemas Equipamentos Eletrônicos Ltda.). The discomfort generated by the electrical current was measured through the application of the visual analog scale (VAS).

### Procedures

All individuals were analyzed in four moments, randomly placed through a draw with an opaque and sealed envelope, on different days of the week, respecting an interval of two to seven days between tests, always performed between 1 and 6 o'clock in the afternoon (figure 1). Moreover, in order to determine the voluntary and electrically-induced torque (MEIT), three measurements were performed, with the highest of the three found values being used for the analyses[18,19].

Torque was determined with the volunteers positioned on the dynamometer's chair, hips immobilized with a belt, at 85° of flexion, and non-dominant limb immobilized with a double cushion on the distal third tibia, 3 cm close to the ankle joint[20]. The trunk was also stabilized with belts in order to avoid possible muscular compensations. The dynamometer was programed at angle velocity of 0° per second (isometric mode), and the knee joint of the dominant leg was positioned at 60° of flexion, and the dynamometer's arm rest was placed on the distal region of the volunteer's leg, which allowed a complete dorsiflexion arch[12,21-23].

During the tests 1 and 2, the volunteers were verbally encouraged
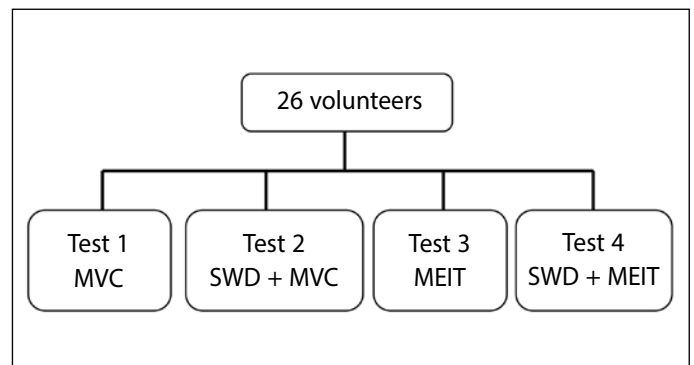


MVC: determination of torque through maximal voluntary isometric contraction; shortwave diathermy (SWD) + maximal voluntary isometric contraction (MVC); maximal electrically-induced torque (MEIT) shortwave diathermy (SWD) + electrically-induced torque (MEIT).

**Figure 1.** Chart of the groups and their respective procedures.

by the examiner to perform the highest strength as possible. Prior to tests 3 and 4, five values proof moments were performed, in which amplitude of electrical current was gradually increased until the maximum the individual could bear. Thus, the highest value the individual could bear was used in all the measurements which applied the neuromuscular electrical stimulation, when the volunteer remained still and with the evaluated limb relaxed for the measurements.

The percentage of the maximal voluntary contraction (MVC) obtained in test 1 was used for normalization of the data obtained in tests 3 and 4. In all tests, before the measurement and in the intervals between measurements, a three-minute time was necessary for the individuals' positioning. This time was necessary so as to avoid fatigue between repetitions. In the intervals between electrically-induced contractions, the visual analog scale (VAS) was shown to the volunteers so that they could identify the discomfort generated by the electrical current. The VAS was a 10-centimeter line where the term "no discomfort" was written on the left extremity and the term "maximal discomfort possible" on the right extremity. Three measurements were analyzed in each test which consisted of three repetitions each and used for analysis the discomfort index presented during the production of the highest MEIT observed between the three repetitions.

### Test 1 – Maximal voluntary contraction (MVC)

Prior to the beginning of the test, the volunteers were told that whenever asked, they should perform the highest strength as possible to extend knee, enabling hence that torque of the quadriceps femoris muscle could be determined through MVC. This procedure was performed three times, with nine seconds of contraction each, with three-minute interval between measurements, in which the individuals remained relaxed. The volunteers were verbally encouraged by the examiner during the tests' performance [24].

### Test 2 – Short wave diathermy (SWD) + maximal voluntary contraction (MVC)

The volunteers were submitted to short wave diathermy application in continuous mode before the MVC evaluation, through coplanar technique during a period of 20 minutes. Capacitive electrodes were used and one of them was placed 3 cm below the antero superior iliac spine and the other 3 cm above the patella base. The volunteers were told to inform the

researcher when the thermal sensation generated by the short wave device was moderate heat (dose III), being this dose kept during the 20 minutes of application.

After this procedure, the individuals were positioned on the isokinetic dynamometer and told that when command was given, they should perform the highest strength as possible so that torque of the quadriceps femoris muscle could be determined (MVC). Three contractions with nine seconds each and interval of three minutes between them were performed. During the tests, the volunteers were verbally encouraged by the examiner.

### Test 3 – Maximal electrically-induced torque (MEIT)

Before the test began, the individuals were positioned on the isokinetic dynamometer and they were asked to maintain the evaluated limb relaxed in order to avoid voluntary contractions during the electrical stimulation until the three minutes of pre-test interval were completed. The torque values obtained were normalized through the percentage of the maximal voluntary contraction obtained in test 1. MEIT was generated with the Endophasys device (KLD® Biosistemas Equipamentos Eletrônicos Ltda.) which emitted rectangular alternating current with carrier frequency of 2,500 Hz, modulated in bursts of 50 Hz and duty cycle of 20%. The self-adhesive electrodes (7.5 x 13 cm) (Axelgaard®, Valutrode) were placed on the motor point of the oblique vastus medialis muscle and on the motor point of the femoral nerve. These points were localized with the use of a universal current generator (Nemesys941P). Each electrically-induced contraction had duration of nine seconds, with three minutes of interval, being the amplitude (intensity) increased until the previously determined value.

### Test 4 – Short wave diathermy (SWD) + maximal electrically-induced torque (MEIT)

The individuals were submitted to the short wave diathermy application before the test, during 20-minute period, with electrodes being placed according to information from test 2. Following the SWD application, the individuals were placed on the isokinetic dynamometer and told to maintain the evaluated limb relaxed so as to avoid voluntary contractions during the electric stimulation. The electrodes of the electric stimulator were positioned on the motor point of the vastus medialis muscle and on the motor point of the femoral nerve, as previously described in test 3. Each electrically-induced contraction had duration of nine seconds, with three minutes of interval, being the current amplitude increased until the previously determined value.

### Statistical analysis

All tests were performed considering bilateral hypotheses and adopting a α = 0.05. Descriptive analysis was initially used to evaluate frequency, mean and standard deviation when data presented normal distribution verified through the Shapiro-Wilk test, median and interquartile interval (IQ) for data with no normal distribution. Student's *t* test was used for the comparison of the torque values means during the MVC and NMES when the groups presented normal distribution, and the Wilcoxon test for the groups which did not present data normal distribution. Discomfort analysis was assessed with the Wilcoxon test. Data was analyzed with the statistical package SPSS, version 12.

## RESULTS

No statistically differences were found in any of the assessed variables (MVC, MEIT, (% of MVC) and sensory discomfort) compared with previous heat application or absence of it (table 1). However, when the subjects were stratified by gender, higher discomfort was observed in the female subjects during MEIT after application of SWD when compared with the male subjects (p = 0.044) (table 2). Increase of MEIT was only observed in male individuals after heat application (p = 0.030) (table 3).

Table 1. Comparison of the MVC, MEIT and sensory discomfort among the individuals who did not undergo application of SWD before the evaluations and after SWD application.

| Variables | No SWD | After SWD | p |
|---|---|---|---|
| MVC (Nm) | 198.5 (147.7 – 292.5) | 212.0 (152.0 – 290.5) | 0.594 |
| MEIT (% MVC) | 28.70 (± 18.29) | 36.76 (± 25.80) | 0.059 |
| MEIT discomfort (punctuation VAS) | 6.2 (4.5 – 7.3) | 6.7 (3.8 – 7.6) | 0.893 |

Data which did not present normal distribution are expressed in median and interquartile interval. Data which presented normal distribution are expressed in mean and standard deviation values. Subtitle: MVC – maximal isometric voluntary contraction; MEIT – maximal electrically-induced torque.

Table 2. MEIT comparison and sensory discomfort among the male and female individuals who did not perform SWD application before the evaluations and after SWD application.

| Variables | Male | Female | p |
|---|---|---|---|
| MEIT (% of MVC) | 23.54 (± 11.93) | 33.87 (± 22.29) | 0.154 |
| MEIT after SWD (% of MVC) | 32.66 (± 20.34) | 40.87 (± 30.59) | 0.428 |
| MEIT discomfort (VAS punctuation) | 6.2 (4.6 – 7.4) | 6.3 (3.9 – 7.7) | 0.687 |
| MEIT discomfort after SWD (VAS punctuation)* | 6.3 (2.6 – 7.0) | 7.6 (4.1 – 9.2) | 0.044 |

Data which did not present normal distribution are expressed in median and interquartile interval. Data which presented normal distribution are expressed in median and standard deviation values. Subtitles: MVC – maximal voluntary contraction; MEIT– maximal electrically-induced torque. * p < 0.05.x

## DISCUSSION

The short wave diathermy effect in the maximal electrically-induced voluntary torque, in the electrically contraction and the discomfort generated by the electrical current were all evaluated in the present study. When data were analyzed considering individuals of both sexes, no differences were found in any of the evaluated variables, while when they were stratified for an analysis separated by sex, MEIT increase was observed after SWD application in the

**Table 3.** Comparison of the MVC, MEIT and sensory discomfort among individuals from the same sex who did not had SWD application before the evaluations and after SWD application.

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| Variables | No SWD | After SWD | p | No SWD | After SWD | p |
| MEIT (% MVC) | 290.0 (256.5 – 333.5) | 284.0 (250.5 – 328.5) | 0.382 | 148.0 (142.5 – 163.5) | 161.0 (115.5 – 192.0) | 0.944 |
| MEIT after SWD* (% MVC) | 23.54 (± 11.9) | 32.66 (± 20.3) | 0.030 | 33.87 (± 22.3) | 40.87 (± 30.6) | 0.365 |
| MEIT discomfort (VAS punctuation) | 6.2 (4.6 – 7.5) | 6.3 (2.6 – 7.1) | 0.124 | 6.3 (3.9 – 7.7) | 7.6 (4.1 – 9.2) | 0.117 |

Data which did not present normal distribution are expressed in median and interquartile interval. Data which presented normal distribution are expressed in mean and standard deviation values. Subtitle: MVC – maximal voluntary contraction; MEIT – maximal electrically-induced torque.* p < 0.05.

male individuals, a fact which was not observed in the women. Moreover, the women presented increase in sensory discomfort during MEIT production after the heat application.

Torque did not change during maximal voluntary contraction aassociated with heat produced by SWD. Such fact can be explained due to the fact there is no need of greater blood, nutrients, ATP or oxygen contribution, since it is a voluntary phasic muscular contraction of high intensity and short duration, in which the proposed interval is sufficient to totally recover the energetic supplies[24]. It is known that heat decreases the firing rate of the type II afferent fibers of the muscle spindle and increases the firing rate of the Ib fibers of the Golgi tendon organs, leading to reduction of firing rate of the alpha and gamma motoneurons, decreasing hence the contractile activity[7,8,25]. These alterations could theoretically reduce the voluntary torque; however, the remaining heat physiological effects, such as metabolism and velocity of nervous conduction increase, should be considered as a whole. The results of the present study corroborate previous research which, despite using different heating methods[11,18], have not found statistically significant differences in the strength voluntarily produced with previous heat application, being possible to observe that the muscular attitude did not suffer great influence of the tissue heating. Only one study using the same heat modality applied in the present study (SWD) was found in the literature[4]. In this investigation, decrease of voluntary torque was observed immediately after the heat application. After 50 minutes, the strength levels reached baseline values and after two hours, they reached values higher than the ones initially measured; that is to say, before the heat application. A possible methodological flaw was the fact that the authors had performed all the strength measurements on the same day. In that case, the onset of fatigue or neuromuscular facilitation could have interfered in the results.

Increase of the neuromuscular system activation threshold due to the increase of blood flow in the adipose tissue may explain the higher discomfort reported by women during the MEIT after heat application when compared with men[26-28]. The discomfort index among men and women during MEIT with no previous heat application was similar, which is in agreement with previous studies which verified higher discomfort in the female sex when the electrical stimulation was performed at the motor threshold;

however, discomfort between genders was similar when the stimulation was performed at the supramotor threshold[29].

When the data are analyzed as a group, no alteration in the MEIT with the application was observed. Nevertheless, when the individuals were stratified by sex, MEIT increase after SWD application was observed in the male individuals, a fact which was not observed in the female group. MEIT increase in the male individuals after heat application may be related to the increase of local metabolism and increase in velocity of nervous conduction. A hypothesis for the MEIT absence of alteration after SWD application in women may be attributed to the fact that men are considered more electrically excitable, exactly for presenting higher quantity of muscular mass and lower quantity of adipose tissue in the gluteofemoral region in comparison with women[30]. We believe that SWD use may have generated higher thermal load in the adipose tissue compared with the muscle tissue, especially in women [8]. This higher fat heating may have led to increase in blood flow and electrical conduciveness in that tissue, causing the electrical current to concentrate even more in that region and increasing hence the activation threshold of the neuromuscular system[28].

The main limitation presented in this study was the lack of measurement of the body composition of the participants. Further studies which investigate the association between body composition and capacity of generating electrically-induced torque after heat application should be carried out. Moreover, studies which investigate whether or not MEIT increase after heat application will generate clinically significant strength increase in these individuals become necessary.

## CONCLUSION

Short-wave diathermy did not influence on the torque generated by voluntary contraction. However, previous application of deep heat produced increase in the electrically-induced torque in male individuals. Additionally, the discomfort produced during electrical stimulation was higher in female individuals after heat application.

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All authors have declared there is not any potential conflict of interests concerning this article.

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