Effects of eight weeks of neuromuscular electrical stimulation training on muscle activation / torque ratios in elderly women with osteoarthritis

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Abstract

Introduction: Aging affects the musculoskeletal system, which can lead to osteoarthritis, causing degeneration of the articular cartilage and consequently resulting in functional impairment among elderly patients. However, neuromuscular electrical stimulation (NMES) training can be used as a mode of muscle strengthening. *Objective:* To investigate the effects of eight weeks of NMES training of the knee extensors on the RMS/torque ratio of elderly persons with osteoarthritis. *Methods:* Twenty-four elderly women were assigned into two groups: a healthy group (HE; n=12) and an osteoarthritis group (OA; n=12). The OA group was submitted to eight weeks of NMES training. *Results:* In the OA group, the RMS values increased from the pre-training to the post-training periods ($p<0.05$). The HE group did not differ from the OA group in the post-training period ($p>0.05$). Quadriceps torque was higher in the OA group in the post-training period at 90° of knee flexion ($p<0.05$) but the torque in the HE group remained higher than in the OA group for all the angles evaluated ($p<0.05$). The RMS/torque ratios increased in the post-training period at 60°, 75° and 90° of knee flexion ($p<0.05$), but did not differ between the HE and OA groups ($p>0.05$). *Conclusion:* Eight weeks of NMES training resulted in a significant increase in the RMS and torque values of the quadriceps, but these neural adaptations were not sufficient to improve the osteoarthritis group to levels similar to the healthy group.

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INTRODUCTION

Aging causes several changes in the musculoskeletal system, such as reduced muscle mass and the loss of muscle activation capacity, causing a decrease in force production capacity.[1,2] This reduction, combined with other factors (changes in bone, cartilaginous and connective tissue) results in imbalances in the musculoskeletal structure, and may cause or aggravate degenerative processes in the same.[3]

Among the various degenerative diseases that affect the elderly, osteoarthritis (OA) is the most prevalent.[4,5] OA is characterized as affecting the chondrocytes and cartilage matrix, resulting in structural and functional losses of cartilage. This process leads to a compensation of bone tissue, causing a remodeling of the same, which may aggravate the degenerative process.[6,7]

One of the joints most affected by OA is the knee joint. OA causes a loss in force production capacity and reduced activation of the muscles that make up the quadriceps, leading to a mechanical overload of the joint due to the inability of the knee extensors to absorb impact during activities of daily living.[8]

Various rehabilitation methods have been proposed to reverse the muscle weakness process. Among these, neuromuscular electrical stimulation (NMES) treatment has been used to reduce the risk factors associated with the development and aggravation of the degenerative processes of OA. Its main objective is to increase the musculature force that is inhibited due to joint pain, through the artificial generation of muscle contractions.[9-14] However, there is little evidence describing the use of NMES and its relation to an improvement in neuromuscular and mechanical properties in elderly patients with OA. Similarly, the effects of NMES training on the root mean square (RMS)/torque ratio have not yet been fully explained.

The hypothesis of the present study was that NMES causes an improvement in the RMS/ torque ratio, resulting in values that are closer to those of healthy elderly persons and that are asymptomatic for OA. Therefore, the aim of this study was to evaluate the influence of eight weeks of NMES training on neuromuscular function, evaluated through the RMS/torque ratios of the knee extensor muscles in elderly women with OA of the knee.

MATERIALS AND METHODS

Sample

A semi-experimental study was performed of 24 elderly patients, chosen from a hospital and two orthopedic clinics. The individuals were intentionally divided into two groups on a paired basis: the osteoarthritis group (OA), n = 12, body mass 76.17 kg (±11.82), height 155.71 cm (±8.00), age 60.17 years (±8.90); and the healthy group (HE, n=12, body mass 66.83 kg (±6.64), height 156.92 cm (±1.98), age 61.50 years (±5.96). The OA group underwent a process of eight weeks of NMES training of the extensor muscles of the knee. Osteoarthritis in the OA group was classified in accordance with Dejour et al.[15] and diagnosed by a physician expert in the field of orthopedic traumatology through x-ray exam and clinical evaluation. Only patients with grade 2 (early arthritis with joint space narrowing on X-ray, subchondral condensation and presence of osteophytes) or 3 (osteoarthritis undergoing rapid evolution, in which joint imbalance can be identified due to the high degree of bone degeneration) osteoarthritis were included in the study. The exclusion criteria were: (1) medical contraindication for participation in maximum stress tests, (2) presence of any neurological, metabolic, cardiovascular or neoplastic disease.

The study was performed at the Neuromuscular Research Laboratory of the School of Physical Education of the Universidade Federal do Rio Grande do Sul (UFRGS). Data collection was carried out between October and December 2012.

The study was approved by the Ethics Research Committee at the Universidade Federal do Rio Grande do Sul (register nº 2007791/2008). All the participants signed a Term of Free and Informed Consent.

Examination procedure

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire[16] was used to evaluate the pain of OA subjects before and after NMES training.

Only the right lower limb of individuals from both groups was examined. A Biodex System 3 Pro brand isokinetic dynamometer (Biodex Medical Systems, Shirley - New York, USA) was used to assess the isometric torque of the knee extensors. Initially, subjects were seated in the chair of the dynamometer and fixed in position with Velcro strips, keeping the hip angle at approximately 90° flexion, and positioning the axis of the knee joint with the rotation axis of the dynamometer.[16]

Prior to performing the tests, a familiarization procedure was performed, which consisted of two series of three concentric repetitions (angular velocities of 120°/s and 60°/s) and an isometric contraction (at an angle of 60° of knee flexion). After familiarization, torque was measured using three maximal voluntary isometric contractions (MVICTs) at an angle of 60°, and an MVICT of the knee extensor muscles (randomized) at angles of 30°, 45°, 75° and 90°. A two-minute interval was provided between consecutive contractions to avoid possible effects of fatigue.

To obtain the electromyographic signal an eight channel electromyography system was used (AMT-8, Bortec Biomedical Ltda., Canada). The electromyographic signal (EMG) was acquired from the rectus femoris, vastus lateralis and vastus medialis muscles through pairs of passive surface electrodes (Meditrace - 100; Ag/AgCl; diameter of two centimeters) in bipolar configuration. The Dataq system (Dataq

Instruments Inc., Akron, USA) was used for data acquisition. The EMG signals and torque were digitized with a frequency of 2000 Hz per channel by a 720-DI analog-to-digital card (Dataq Instruments Inc., Akron, USA). The EMG signals were mathematically processed using a Matlab® routine. First, the signals were filtered with a third order Butterworth passband filter with a cutoff frequency of 20 to 500 Hz. After filtration, the root mean square (RMS) values of each portion of the quadriceps muscle were calculated. The average of the RMS values of the three portions of the quadriceps muscle was considered the activation of the knee extensors.

Muscle strengthening procedure

To identify the motor point an electrical stimulator with a stylus was used, employing faradic current of sufficient intensity and frequency to produce a tetanic contraction (with a frequency higher than 30 Hz) (EGF Carci, SP, Brazil). NMES was used for muscle strengthening, with a two-phase symmetrical current with frequency of 80 Hz and pulse width of 500µs, using a portable electrical stimulator specially developed for the study (UFRGS, RS, Brazil). The participants remained seated with knee flexion of 90° and adhesive electrodes (Valutrode, dimensions 10x5 cm) were positioned proximally on the skin covering the motor point and the distal portion, and the skin covering the distal extremity of the quadriceps muscle (5 cm above the border of the patella). The stimulus was applied to the motor point of the quadriceps muscle for a period of 10 seconds followed by an initial resting time of 50 seconds. The training consisted of three weekly sessions over a period of eight weeks, with variations in the duration of sessions (initially 18 minutes, increasing by two minutes a week, finishing at 32 minutes) and rest periods (initially 50 seconds, reduced by 10 seconds every two weeks of training, finishing at 20 seconds of rest) during the training period.[16]
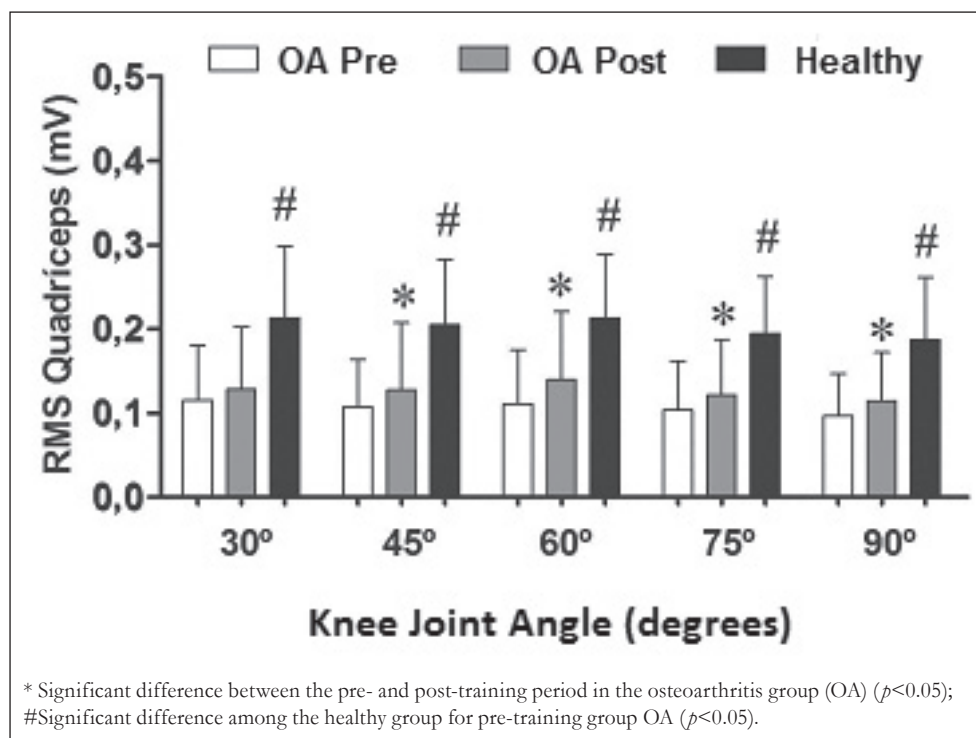
Statistical analysis

Data was expressed as means and standard deviations of the RMS/torque ratio and muscle activation (mean RMS) of three portions of the quadriceps (rectus femoris, vastus lateralis and vastus medialis) at angles of 30°, 45°, 60°, 75° and 90° of knee flexion. The dependent t-test was used to compare the results of the OA group pre and post-training. To compare the OA group and the HE group the Levene test was used to test the homogeneity of the data, followed by an independent t-test. The SPSS 10.0 software for Windows program with a significance level of p<0.05 was used for statistical analysis.

RESULTS

The results of the WOMAC16 questionnaire showed that there was a reduction in pain from the pre- (11.7±3.2) to the post-NMES treatment period (7.2±3.5); $p<0.01$.
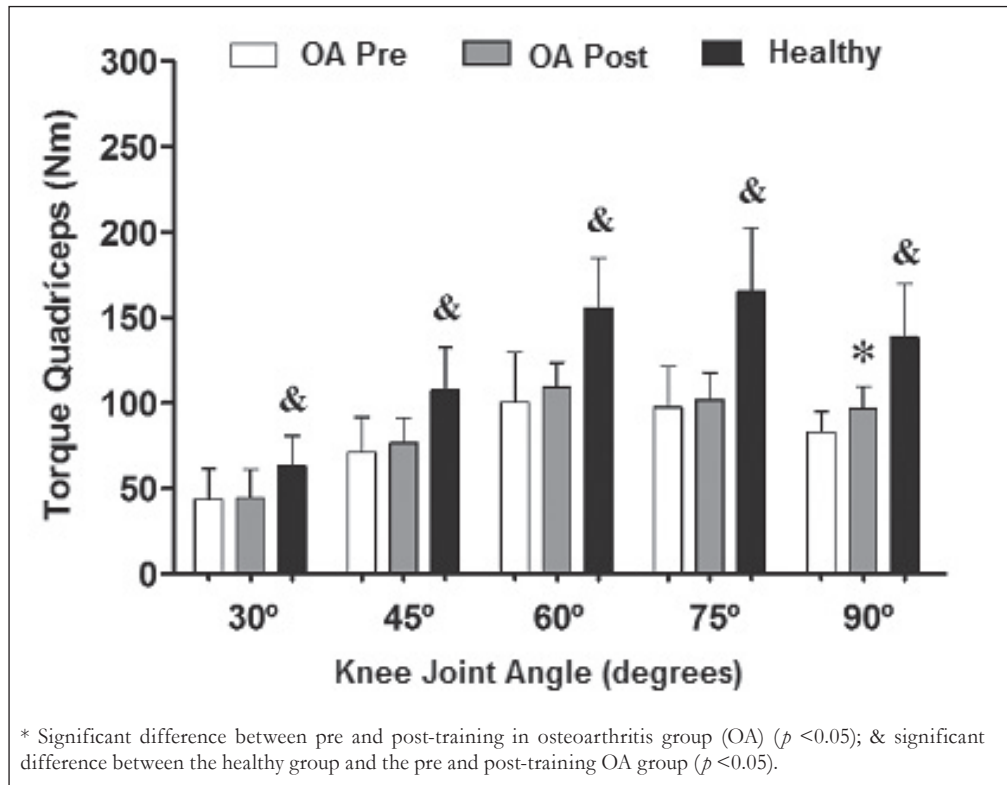
The RMS value of the quadriceps in the OA group increased after eight weeks of NMES training at angles of 45° ($p=0.04$), 60° ($p<0.01$), 75° ($p=0.01$) and 90° ($p<0.01$) before and after training. The HE group had a greater RMS value than the pre-training value of the OA group for all joint angles ($p=0.03$). No significant differences were observed during the post-training period ($p>0.05$). (Figure 1).

* Significant difference between the pre- and post-training period in the osteoarthritis group (OA) ($p<0.05$);
#Significant difference among the healthy group for pre-training group OA ($p<0.05$).

Figure 1. Mean RMS values (mV) of the knee extensor muscles (quadriceps) at different joint angles. Porto Alegre, RS, 2012.

The torque produced by the knee extensors in the OA Group increased significantly at the 90° angle following the training period ($p = 0.03$).

The HE group had higher torque values than the OA group for all joint angles both pre- and post-training ($p = 0.04$). (Figure 2).

* Significant difference between pre and post-training in osteoarthritis group (OA) ($p <0.05$); & significant difference between the healthy group and the pre and post-training OA group ($p <0.05$).

Figure 2. Maximum isometric torque of the knee extensors (quadriceps) at different angles. Porto Alegre, RS, 2012.

Regarding the RMS/torque ratio of the knee extensors, an increase in the ratio at the angles 60° ($p = 0.03$), 75° ($p = 0.02$) and 90° ($p = 0.04$) was observed in the OA group after muscle strengthening with NMES. There was no significant difference between the OA and the HE group pre- and post-training for the ratios at the assessed angles ($p>0.05$). (Figure 3).
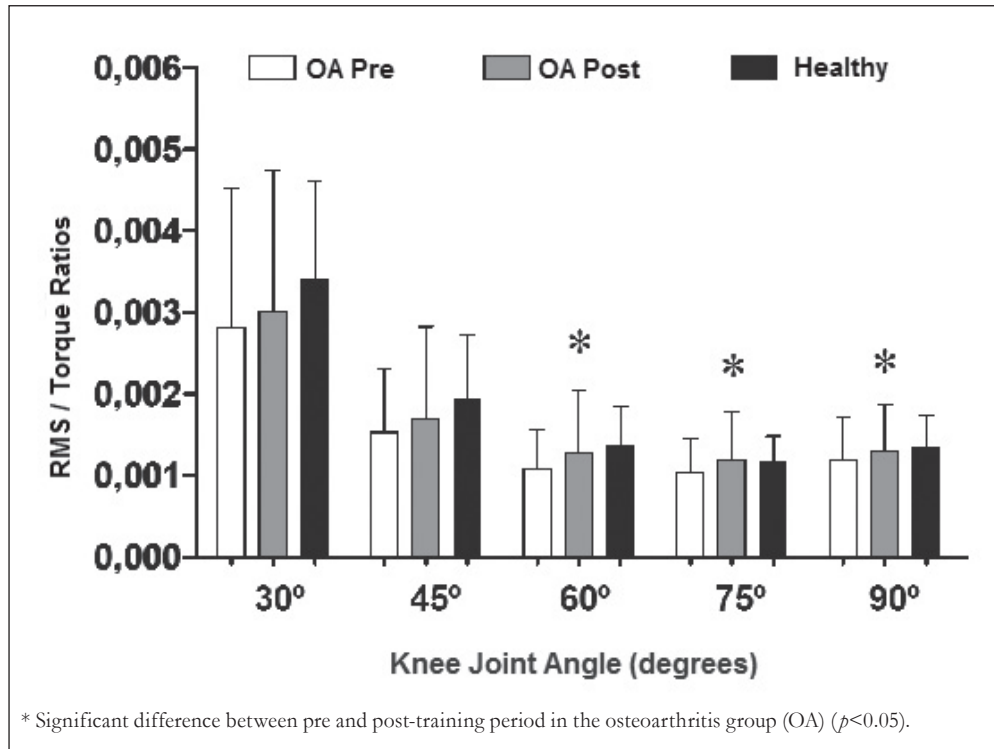
Figure 3. Root mean square (RMS)/torque ratios of the knee extensors at different angles. Porto Alegre, RS, 2012.

DISCUSSION

Despite using older patients, the results of the present study agreed with the findings of Gondin et al.,[17] which also observed an increase in the electrical activity of the muscles of younger individuals after eight weeks of training with artificial electrical stimulation. The HE group revealed greater electrical activation than the OA group during the pre-training period, but there was no difference between the groups in the post-training period, suggesting that training with NMES increases muscle electrical activity, achieving levels close to those of healthy individuals.

Bennell & Hinman[18] suggested that aging causes specific adaptations, resulting in degeneration of the bone, cartilage, connective and muscular tissue. These degenerative factors (sarcopenia, loss of muscle strength and decreased muscle activation) are possible causes of OA, which in turn generates dysfunction, inhibition, and reduction of muscle force and activation.

The increase in torque at the 90° angle observed after the training period suggests that there was an improvement in muscle function with NMES training. The RMS/torque ratios increased after the training period at angles of 60°, 75° and 90°, indicating partial improvement

of neuromuscular function, suggesting that the ratios also increase at angles close to the training angle. The absence of differences between the OA and HE groups suggests that the behavior of RMS/torque ratios was similar between the groups. However, it should be pointed out that muscle activation and the torque of the knee extensors were lower in the OA group than in the HE group.

Rosemffet et al.[14] used a procedure with a short resting time (5 sec) and found an increase in force production after training with artificial electrical stimulation. The higher torque observed in the HE group may be explained by greater motor unit recruitment. Petterson et al.[19] pointed out that subjects with OA have degeneration of the involved joint, causing joint instability, generating muscle inhibition and loss of force production capacity.

In addition, the results of this study partly corroborate those of Bruce-Brand et al.,[20] which identified improved functional ability and reduced pain after eight weeks of training with artificial electrical stimulation. However, these authors found no significant increase in isometric torque after eight weeks of training, a finding which differs from the results of the present study, in which there was a significant increase in isometric torque at the training angle after NMES training. These results may be related to the lower training time per-session and maintenance of the same training parameters for every session, without changing volume and intensity, used by Bruce-Brand et al.,[20] compared to the present study.[16,21,22]

In contrast, the present study conducted NMES training with only one knee flexion angle (90°), which resulted in increased torque after the training period solely for this angle, representing a possible limitation of the study. In order to optimize NMES training, it is suggested that in future studies such training is performed at more than one joint angle (such as 30°, 60° and 90° of knee flexion), facilitating gains in torque for the largest possible joint amplitude, hence improving the performance of daily living activities of individuals with OA. In addition, studies that seek to review functional parameters before and after training with NMES, such as the Timed Up and Go, Romberg and Sit and Raise tests, are also required, in order to evaluate the beneficial effects of such training on the functional capacity of older adults with osteoarthritis.[20-23]

CONCLUSION

Eight weeks of neuromuscular electrical stimulation training resulted in increased muscle activation at angles of 60°, 75° and 90°, and in the torque produced by the knee extensor muscles at the trained angle (90°) in the osteoarthritis group. These neural adaptations were not enough to improve the muscle activation and production of torque of elderly persons with knee osteoarthritis to a level similar to healthy elderly individuals. However, the increased muscle activation and torque of the osteoarthritis group after training did not change the root mean square (RMS)/ torque ratio, with similar values maintained for both the healthy and osteoarthritis groups.

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