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Short-term effects of neuromuscular electrical stimulation and ultrasound therapies on muscle architecture and functional capacity in knee osteoarthritis: a randomized study

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Abstract

Objective: To determine the effects of ultrasound therapy and neuromuscular electrical stimulation (NMES) application on the muscle architecture and functional capacity in patients with knee osteoarthritis.
Design: A randomized study.
Subjects: A total of 60 patients with knee osteoarthritis.
Interventions: Participants were randomized into one of the following two intervention groups, five days a week, for three weeks: the combination of NMES application, hot pack, and exercise therapy was applied to the NMES group. The combination of therapeutic ultrasound, hot pack and exercise therapy was applied to the ultrasound therapy group.
Main measures: Subjects were evaluated for pain and functional capacity with the use of the visual analog pain scale (VAS), Western Ontario and McMaster Universities Arthritis Index (WOMAC), and 15 meter walking test. The muscle architecture (muscle thickness, pennation angle and fascicle length) was assessed from vastus lateralis and quadriceps femoris muscles bilaterally by ultrasonography.
Results: Two groups presented significant improvements in all outcome measures before and after treatment ($P < 0.01$). There were significant improvements in VAS rest pain ($P < 0.05$), VAS activity pain ($P < 0.05$), WOMAC pain ($P < 0.05$), WOMAC stiffness score ($P < 0.05$), and WOMAC physical function ($P < 0.05$) for the ultrasound therapy group in comparison to the NMES group. NMES group exhibited more increases in the muscle thickness and fascicle length values when compared to ultrasound therapy group ($P < 0.05$).
Conclusion: Ultrasound therapy appears to be an effective treatment in reducing pain and improving functional capacity. NMES application has more effects on the muscle architecture.

Keywords

Neuromuscular electrical stimulation, ultrasound therapy, knee osteoarthritis, functional capacity

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Introduction

Knee osteoarthritis is a disease that can be characterized as clinical symptoms that are morning stiffness, decreased range of motion, chronic joint pain, and muscle weakness, and may contribute to important functional limitations that occur with disease progression.[1] Increased functional limitations have been reported to lead to a vicious cycle of pain–weakness–pain in patients with knee osteoarthritis.[2] Knee extensor strength is an important factor determining independence in elderly individuals.[3] Therefore, muscle strengthening is an important point in the rehabilitation program. Muscle weakness has been reported to be associated with decreased muscle mass. Muscle thickness and anatomical cross-sectional area have been decreased in osteoarthritis patients.[4,5] Furthermore, evidences suggest that quadriceps muscle weakness may contribute to worsening of knee pain and was associated with increased risk for tibiofemoral and knee joint space narrowing.[6,7] It has been suggested that quadriceps weakness is related to functional capacity and disability.[8]

Neuromuscular electrical stimulation which is a method of physical therapy can be used for functional training or activity to replace loss of function.[9] Neuromuscular electrical stimulation has been demonstrated to improve quadriceps femoris muscle strength in various pathological knee conditions.[10] Therapeutic ultrasound is one of the used physical modalities of physiotherapy for treatment of knee osteoarthritis.[11] Ultrasound therapy has shown a significant increase in the range of motion of the knee, decreasing pain intensity, and increasing muscle strength in patients with knee osteoarthritis.[12] In order to exactly evaluate muscle architectural parameters, ultrasonography was shown as a proper monitoring method.[13] The aim of this study was to compare the effectiveness of therapies of neuromuscular electrical stimulation and ultrasound, for improving muscle architecture, pain, and functional capacity in patients with knee osteoarthritis.

Methods

Trial design

This study was a randomized controlled trial. This study was approved by the University's Ethics in Research Committee (Protocol number 2016/92). All patients signed a written consent form prior to data collection. The treatment period lasted three weeks. The participants were assessed at two different time-points (before–after treatment) over a three-week period.

Participants

A total of 60 patients who fulfilled the American College of Rheumatology[14] for knee osteoarthritis were enrolled in this study. Patients have grade 2 or 3 knee osteoarthritis according to the criteria proposed by Kellgren and Lawrence.[15] Patients with cardiovascular, inflammatory, infectious diseases, causes of lower extremity weakness, tumoral diseases, participation in a strength training program or physiotherapy treatment for knee osteoarthritis in the past six months, knee surgery, and intra-articular injection in the past six months have been excluded.

Randomization

All participants who were satisfied with the inclusion criteria were randomly assigned to one of the following two study groups: Group 1—ultrasound therapy group and Group 2—the neuromuscular electrical stimulation application group. Group allocation was randomized in two blocks of 30 sealed envelopes without external marks, which were mixed and numbered from 1 to 30, containing a piece of paper with the group allocation. The researchers responsible for outcome measures and ultrasonograhic measurements were blinded to the patients' diagnosis or intervention (Figure 1). All participants received treatment, and the outcome measures were included in the data analysis.

Intervention protocols

Patients in Group 1 received 15 sessions distributed over three weeks (five days per week) of ultrasound therapy, hot pack, exercise, and analgesic (paracetamol; 1500 mg/day) treatment, while the Group 2 patients received neuromuscular electrical stimulation application, hot pack, exercise, and analgesic (paracetamol; 1500 mg/day) treatment. Continuous ultrasound therapy

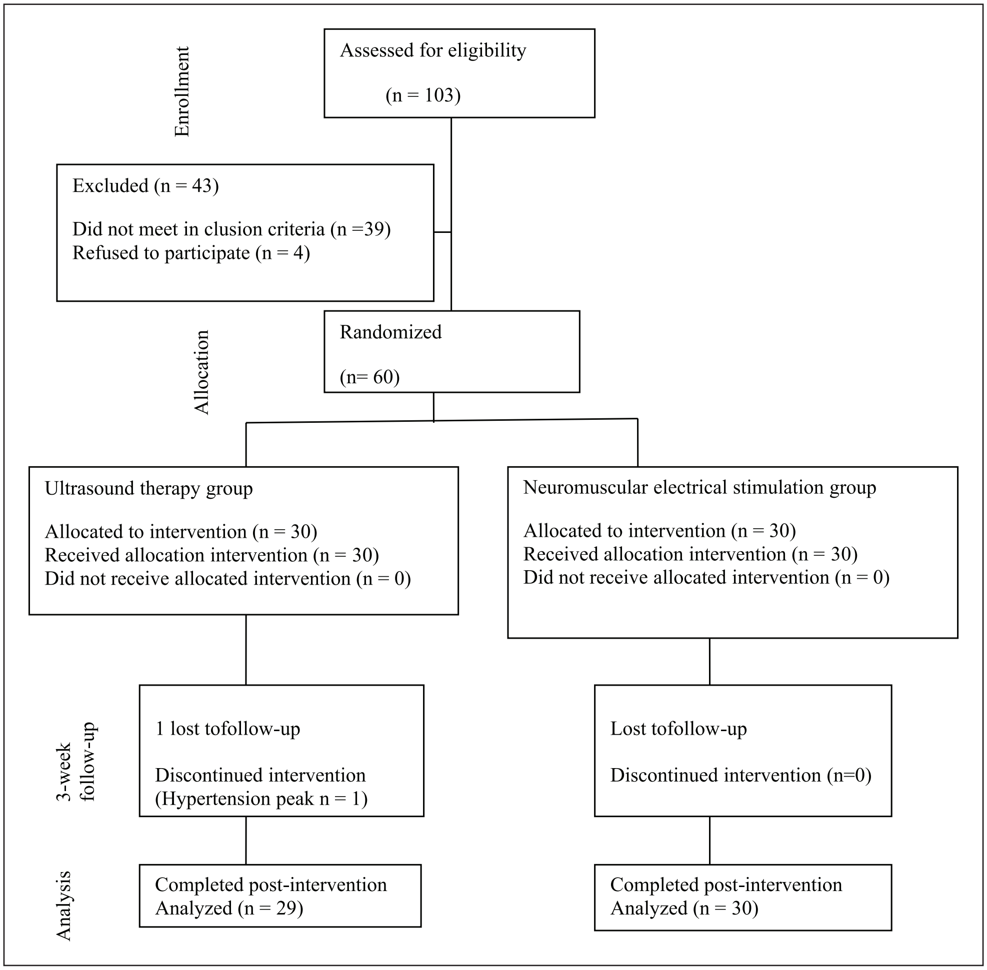

Figure 1. Flowchart of the patients randomized and analyzed per group.

(Chattanooga, 1 watt/cm^2 dose, 1 MHz, 5 minutes) was applied with a 5-cm diameter applicator (Chattanooga intelect advanced) bilaterally to the knees of each subject for three weeks. These treatment parameters were decided on according to previous studies.[16] A Cefar device (Cefar, European Union) was used to perform the neuromuscular electrical stimulation application. The intervention was performed with subjects seated on a regular chair (hip at 90° and knee at 60° of flexion), and two self-adhesive electrodes (Valotrude self-adhesive electrode; 7.5 × 13 cm) were used, neuromuscular electrical stimulation was applied bilaterally to vastus lateralis and quadriceps femoris muscles for 20 minutes/session, once daily, five days a week, for three weeks. The parameters used were as follows: frequency of 50 Hz; pulse duration of 250 microseconds; time on: 10 seconds; and time off: 30 seconds. The intensity of the neuromuscular electrical stimulation used in the treatment was the maximum tolerated by each patient.[17]

Evaluation protocol

The demographic data of the patients were recorded, and clinical measurements were assessed at baseline and after the treatment. The outcome measures were pain, 15 meter walking test, Western Ontario and McMaster Universities Arthritis Index (WOMAC), and muscle architecture (muscle thickness, fascicle length, and pennation angle).

Pain at rest and at movement was evaluated with visual analog scale.[18] Pain was assessed using a 0–10 visual analog pain scale, with 0 meaning "no pain" and 10 meaning "excruciating pain."

The WOMAC includes 24 items that are separated into three subscales (pain, stiffness, and physical function scales). WOMAC which are liable index for use in Turkish patients with knee osteoarthritis and standing-up from a chair, and 15 meter walking test were used to measure for changes in functional capacity.[19,20]

Muscle architecture measure was performed using an ultrasound device. Images acquisition were performed by the same trained sonographer with an ultrasonographic system working in B-Mode (GE Logiq P6, Wisconsin, USA) with a 7.5-MHz linear array probe. With the patients at standing position, the examiner marked one point at 50% of the length of the thigh, determined by the distance between the greater trochanter and the lateral condyle of the femur. After which, the subject laid with the legs relaxed in supine position for 10 minutes before image acquisition on the legs. The probe was positioned along the direction of the fascicles, where the fascicular organization between the superficial and deep aponeurosis on the muscle was better determined. Muscle measurements were made before and after treatment. Fascicle length, pennation angle, and muscle thickness were measured at three times and the mean value was noted. Muscle thickness was measured as the mean distance between the superficial and deep aponeurosis at both image muscles. The distance between the intersection composed of the superficial aponeurosis and muscle fascicle, and the intersection composed of the deep aponeurosis and muscle fascicle was defined as muscle fascicle length. The angle between the muscle fascicle and deep aponeurosis was defined as pennation angle.[13,21] Figure 2 shows ultrasonographic measurements of muscle architecture.

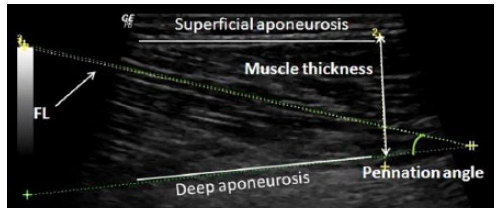

Figure 2. Ultrasonographic imaging of muscle demonstrating the measurement of the pennate angle, muscle thickness, and fascicle length.

Statistical analysis

Paired samples *T* test was used to verify the differences between the pretreatment and posttreatment tests in both group. Independent Student's *t*-tests were used to quantify possible differences in all outcome measures between ultrasound therapy group and neuromuscular electrical stimulation application group in the study. Results were expressed as mean value ± standard deviation (SD). *P*-values less than 0.05 were considered statistically significant.

Results

A total of 60 patients with knee osteoarthritis were enrolled in this study. The mean age of the ultrasound therapy group and neuromuscular electrical stimulation group were 62.86 ± 8.11 and 61.23 ± 7.36 years, respectively. Mean duration of disease for the ultrasound therapy group and neuromuscular electrical stimulation group were 6.96 ± 3.64 and 5.76 ± 3.33 years, respectively. No significant differences were found in demographic characteristics and clinical measurements of the study groups ($P > 0.05$; Table 1). There were statistically significant improved functional capacity, pain, and changes in the muscle architecture in two groups after treatment ($P < 0.01$; Table 2), ($P < 0.01$, pennation angle, except, $P > 0.05$; Table 3). However, there were statistically significant differences in functional capacity and pain (WOMAC and visual analog scale) in ultrasound therapy group compared to neuromuscular electrical stimulation application

Table 1. Demographic characteristics of the study groups.

Variables	Group ultrasound therapy ($n=30$); mean (SD)	Group NMES ($n=30$); mean (SD)
Age (years)	62.86 ± 8.11	61.23 ± 7.36
Gender (*n*)		
Women	24	23
Men	6	7
Body mass index (kg/m^2)	28.89 ± 2.59	29.98 ± 3.35
KL grade	2.63 ± 0.49	2.46 ± 0.50
Disease duration (years)	6.96 ± 3.64	5.76 ± 3.33

KL: Kellgren Lawrence; NMES: neuromuscular electrical stimulation; SD: standard deviation.
*$P < 0.05$.

group after the treatment ($P < 0.05$; Table 2; walking test, except, $P > 0.05$). Furthermore, there was a significant muscle architecture increase after three weeks of intervention in the neuromuscular electrical stimulation application group compared to the ultrasound therapy group after the treatment (pennation angle, except, $P < 0.05$; Table 3).

Discussion

This study aimed to compare the effects of neuromuscular electrical stimulation and ultrasound therapy on improvement of functional capacity and muscle architecture, through functional tests, functional questionnaires, and ultrasonograhic measurements. In accordance with our hypothesis, this clinical trial showed that neuromuscular electrical stimulation was more effective with regard to improvement of muscle architecture, but ultrasound therapy was more effective with regard to improvement of functional capacity and pain.

Knee osteoarthritis is a common musculoskeletal system disease. Knee osteoarthritis can lead to disability and is an important health problem.[22] Muscle weakness in knee osteoarthritis has been suggested to be associated with physical inactivity, more severe joint degeneration, higher pain, and symptomatic progression of the disease.[23] Although the effect of ultrasound therapy on reducing pain in patients with knee osteoarthritis is not fully described, it could be associated with a decrease in function of the sodium/potassium pump in the pain conduction fibers. Furthermore, the ultrasound therapy has biophysical effects that increased capillary permeability and tissue metabolism, increasing of fibrous tissue extensibility.[24,25] Zhang et al.[26] and Yildiz et al.[27] demonstrated that ultrasound therapy is an effective treatment for reducing the pain and improving physical function in patients with knee osteoarthritis. However, Cakir et al.[28] suggested that ultrasound therapy provided no additional benefit in improving pain and functions in addition to exercise training. Impaired spinal reflex and excitability of spinal cord can cause limitation in the activation of alpha motoneurons (α-MN) of the joint-related muscles in joint pathologies. This leads to the production of a continuous reflex inhibition known as arthrogenic muscle inhibition and consequent reduction in efferent motor neuron stimulation of the muscle.[29] Ultrasound therapy could be attributable to a reverse effect on arthrogenic muscle inhibition and could be faciliated motoneuron pool excitability.[30] Rodríguez et al.[31] reported that ultrasound therapy could be efficacious for decreasing pain and could increase quadriceps muscle strength and functional improvement in knee osteoarthritis. We found statistically significant differences in pain relief and improving functional capacity in ultrasound therapy group after treatment. We think that because the vicious cycle was blocked with the analgesic impact that ultrasound treatment was formed and physical activity that decreased depending on the pain, this condition has a positive contribution to functional capacity. Furthermore, we found that assessment of ultrasonographic evaluation of muscle architecture showed significant differences as well. These results may be related to a reverse effect of ultrasound therapy over the arthrogenic muscle inhibition.

The pain relief effect of neuromuscular electrical stimulation may be related to the gate-control theory of Melzack and Wall.[32] Gaines et al.[33] compared home-based neuromuscular electrical

Table 2. Clinical measurements before and after treatment.

Variables	Group ultrasound therapy (n = 30); mean (SD)	Group NMES (n = 30); mean (SD)
Baseline		
VAS rest pain	3.10 ± 0.80	3.03 ± 0.85
VAS activity pain	6.10 ± 0.99	5.96 ± 1.12
Posttreatment		
VAS rest pain	1.10 ± 0.30*†	1.33 ± 0.47†
VAS activity pain	2.46 ± 0.68*†	3.00 ± 0.90†
Baseline		
Walk test (seconds)	14.56 ± 3.18	13.89 ± 2.84
Posttreatment		
Walk test (seconds)	12.25 ± 2.72†	11.26 ± 2.52†
Baseline		
WOMAC pain	9.16 ± 2.47	8.93 ± 2.13
WOMAC stiffness score	3.56 ± 0.81	3.40 ± 0.85
WOMAC physical function	34.26 ± 5.85	32.73 ± 6.57
Posttreatment		
WOMAC pain	4.16 ± 1.51*†	5.10 ± 1.78†
WOMAC stiffness score	1.26 ± 0.44*†	1.53 ± 0.50†
WOMAC physical function	12.10 ± 2.42*†	13.26 ± 1.79†

VAS: visual analog scale; NMES: neuromuscular electrical stimulation; SD: standard deviation; WOMAC: Western Ontario and McMaster Universities Arthritis Index.
*$P < 0.05$ (ultrasound therapy group vs NMES group); †$P < 0.01$ (posttreatment vs baseline).

stimulation for the quadriceps muscle with an education group. In the postintervention, they found decrease in pain in a short time after neuromuscular electrical stimulation application of the quadriceps femoris muscle in older adults with osteoarthritis of the knee. Furthermore, Imoto et al.[34] suggested that neuromuscular electrical stimulation, combined with rehabilitation for knee osteoarthritis patients, is effective for improving pain, function, and activities of daily living. However, Talbot et al.[35] reported improvement in pain and functional tests in neuromuscular electrical stimulation group and education group in older adults with osteoarthritis of the knee, but no significant differences were observed between the groups. Electrical stimulation could contribute to increase in the muscle strength changes in muscle fiber composition and capillary system structure. It causes to improve the muscle atrophy due to the prolonged immobilization.[32] Neuromuscular electrical stimulation is an addition to isometric exercises and is alone in patients with cardiovascular disease. Motivation and concentration difficulties could be used for quadriceps strengthening, improving knee osteoarthritis symptoms, and quality of life.[36] Karabay et al.[37] have shown that neuromuscular electrical stimulation application on tibialis anterior and gastrocnemius muscles could be increased in cross-sectional area of muscles in children with cerebral palsy. Vaz et al.[38] demonstrated that neuromuscular electrical stimulation training increased vastus lateralis thickness and fascicle length and improved functional status in patients with knee osteoarthritis. Melo Mde et al.[39] found that neuromuscular electrical stimulation was significantly increased in the muscle thickness and pennation angle values compared to low-level laser therapy group in patients with knee osteoarthritis. The results of above studies confirm that neuromuscular electrical stimulation application is an effective strategy for improving the muscle atrophy associated with knee osteoarthritis. As far as we know, there is no research

Table 3. Ultrasonographic parameters regarding muscle architecture before and after treatment.

Variables	Group ultrasound therapy ($n = 30$); mean (SD)	Group NMES ($n = 30$); mean (SD)
Baseline		
Vastus lateralis muscle (right)		
PA, (°)	15.49 ± 1.34	15.42 ± 1.05
FL, mm	52.51 ± 7.51	53.60 ± 5.67
MT, mm	10.40 ± 1.57	11.13 ± 1.24
Posttreatment		
Vastus lateralis muscle (right)		
PA, (°)	15.50 ± 1.33	15.42 ± 1.05
FL, mm	52.81 ± 7.52†	56.35 ± 5.74*†
MT, mm	11.74 ± 1.36†	12.53 ± 1.00*†
Baseline		
Vastus lateralis muscle (left)		
PA, (°)	15.53 ± 1.20	15.41 ± 1.06
FL, mm	52.84 ± 7.32	53.71 ± 5.80
MT, mm	10.67 ± 1.48	11.22 ± 1.21
Posttreatment		
Vastus lateralis muscle (left)		
PA, (°)	15.55 ± 1.22	15.43 ± 1.07
FL, mm	53.08 ± 7.18†	56.58 ± 5.92*†
MT, mm	11.94 ± 1.40†	12.74 ± 1.04*†
Baseline		
Rectus femoris muscle (right)		
PA, (°)	14.29 ± 0.69	14.70 ± 0.80
FL, mm	59.45 ± 3.95	59.64 ± 3.92
MT, mm	15.19 ± 2.15	15.99 ± 1.94
Posttreatment		
Rectus femoris muscle (right)		
PA, (°)	14.29 ± 0.68	14.52 ± 1.99
FL, mm	60.05 ± 3.85†	62.04 ± 3.70*†
MT, mm	15.64 ± 2.22†	17.08 ± 1.81*†
Baseline		
Rectus femoris muscle (left)		
PA, (°)	14.33 ± 0.69	14.21 ± 0.82
FL, mm	59.48 ± 5.55	59.63 ± 3.92
MT, mm	15.39 ± 2.06	15.92 ± 2.01
Posttreatment		
Rectus femoris muscle (left)		
PA, (°)	14.33 ± 0.70	14.21 ± 0.82
FL, mm	59.86 ± 5.61†	61.44 ± 4.58*†
MT, mm	16.10 ± 2.06†	17.26 ± 1.99*†

MT: muscle thickness; FL: fascicle length; PA: pennation angle; NMES: neuromuscular electrical stimulation; SD: standard deviation.
*$P < 0.05$ (NMES group vs ultrasound therapy group); †$P < 0.01$ (posttreatment vs baseline).

that is compared with neuromuscular electrical stimulation treatment and ultrasound treatment in knee osteoarthritis in literature. We have determined that neuromuscular electrical stimulation can be effective in improving pain and functional capacity in this study in patients with knee osteoarthritis. Furthermore, we found statistically significant differences for muscle architecture in neuromuscular electrical stimulation application group according to ultrasound therapy group. The positive impact of neuromuscular electrical stimulation application on muscles were shown with ultrasonographic measurement in our study. In order to strengthen the muscles and minimize muscle atrophy that may be seen in the patient, neuromuscular electrical stimulation application can be suggested as an effective treatment in knee osteoarthritis. However, further long-term and a large sample size studies are needed to confirm the effect of neuromuscular electrical stimulation application on change of muscle architecture.

Other results of this study were that WOMAC, visual analog scale (rest-activity), and functional assessment scores improved significantly in both groups, but these results were statistically more significant in the ultrasound therapy group (except, walking test). Because our patients with both groups were treated with hot packs and exercise simultaneously, we cannot attribute the abovementioned developments with only ultrasound therapy or neuromuscular electrical stimulation application. Hot packs and exercise may be positively effective on pain and functional capacity.

We realize that the present preliminary study has some limitations. The lack of long-term follow-up and sample size can be considered as the major limitations of this study. There was no control group in our study. In literature, there are a few things guiding for what will the neuromuscular electrical stimulation application severity and the optimal dose of ultrasound treatment be. Likewise, the intensity of applied ultrasound treatment, the size of the treated region or the duration of the treatment indicated variability among different studies. We did not make the power analysis in our study, and type 2 error may have affected the study results.

Both treatment methods can be used as an effective treatment choice in patients with knee osteoarthritis. At the same time, they were safe and easy to implement methods. According to the results of this study, neuromuscular electrical stimulation application seems to be a more suitable treatment in patients with knee osteoarthritis with muscle weakness.

Clinical Messages

- Ultrasound therapy and neuromuscular electrical stimulation application have positive effects on pain, functional capacity, and muscle mass in patient with knee osteoarthritis.
- Ultrasound therapy is a more effective treatment to reduce pain and improve functional capacity in patients with knee osteoarthritis.

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Declaration of Conflicting Interests

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