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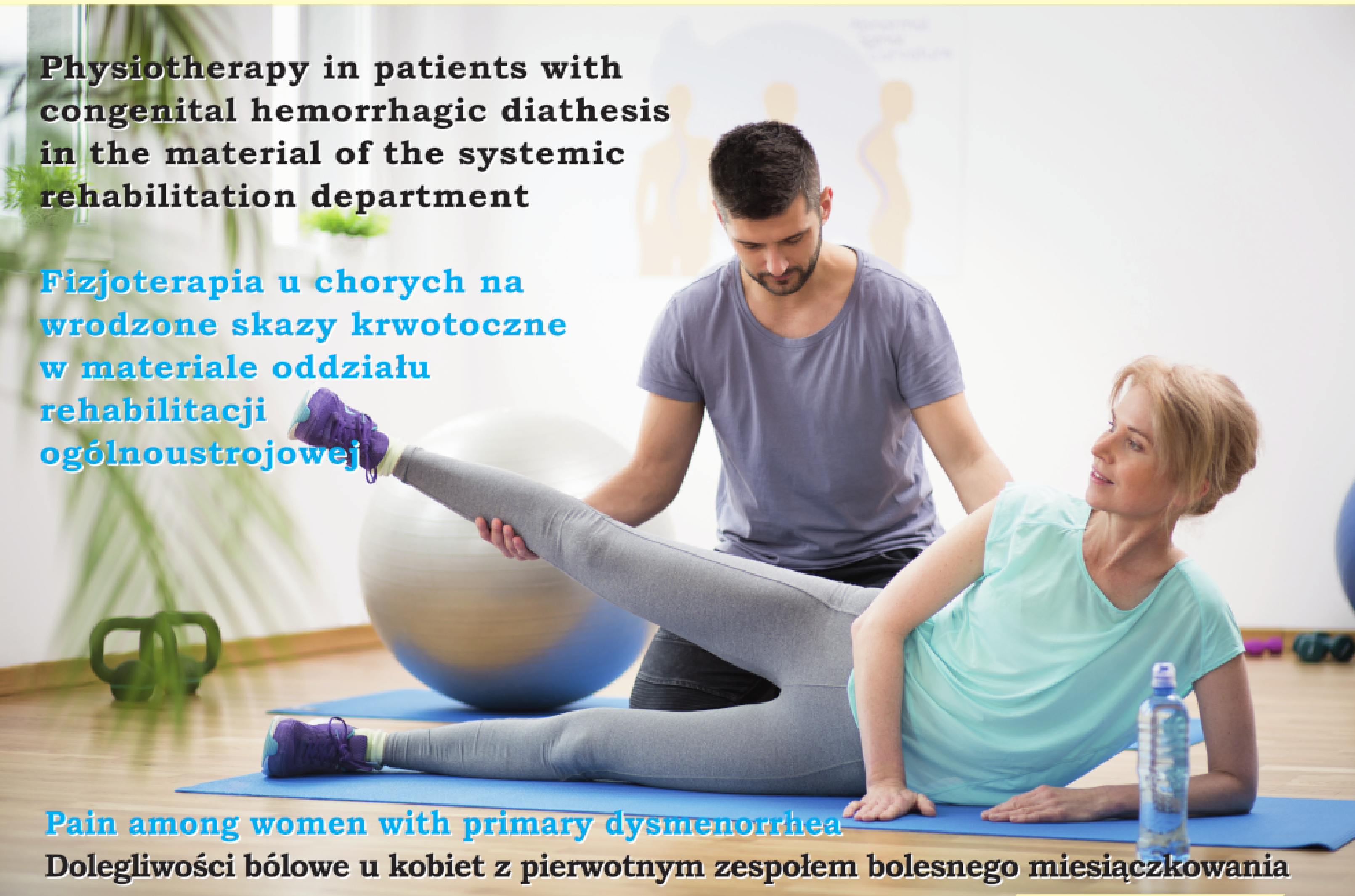

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Static Magnetic Stimulation Versus Conventional Treatment on Cross Sectional Area of Quadriceps Muscle in Knee Osteoarthritis Patients: A Randomized Controlled Study

Statyczna stymulacja magnetyczna a leczenie konwencjonalne dotyczące przekroju poprzecznego mięśnia czworogłowego u pacjentów z chorobą zwyrodnieniową stawów kolanowych: randomizowane badanie kontrolowane

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Abstract

Background. Quadriceps femoris muscle significantly affected knee osteoarthritic patients. Weakness and atrophy occur as a result of muscle unloading and dysfunction. As the maximum force produced by a muscle has a direct proportion to its cross-sectional area (CSA), the current study revealed that static magnetic stimulation (SMS) is beneficial for improving CSA of the quadriceps muscle. Purpose. To examine the influence of magnetic stimulation on CSA of the quadriceps muscle in knee osteoarthritis patients and hence knee function. Materials and Methods. This study adopted a randomized controlled trial design. Twenty-four patients with both knee osteoarthritis (Grades II and III) participated. The participants, aged between 45–55 years, were randomly assigned to two groups. Group (A) received magnetic first stimulation in addition to selected physical therapy consisting of ultrasound device and isometric exercise for quadriceps. Group (B) received selected physical therapy consisting of ultrasound device and isometric exercise for quadriceps only. Two therapeutic sessions were given weekly for three consecutive weeks. Outcome measures were CSA of quadriceps at both sides and Lysholm knee scoring for assessment of the functional ability of the knee joint. These measures were taken before and after three consecutive weeks of intervention. Results. Within groups, the analysis showed a statistically significant increase for all measured variables in the two studied groups ($p < 0.05$). Between groups, the analysis revealed that quadriceps at both side and Lyshlom were significant increase in group (A) compared to group (B). Conclusions. Adding SMS to quadriceps strengthening exercises improved the CSA of quadriceps, which protects muscle from being atrophied and hence improved the knee joint functions more than quadriceps strengthening exercises alone.

Key words:

Electromyostimulation, Knee osteoarthritis, Quadriceps femoris, Strengthening exercises

Streszczenie

Informacje wprowadzające. Mięsień czworogłowy uda miał istotny wpływ na pacjentów z chorobą zwyrodnieniową stawu kolanowego. Osłabienie i atrofia powstają w wyniku odciążenia i dysfunkcji mięśni. Ponieważ maksymalna siła wytwarzana przez mięsień jest wprost proporcjonalna do jego przekroju poprzecznego (CSA), niniejsze badanie wykazało, że statyczna stymulacja magnetyczna (SMS) jest korzystna dla poprawy CSA mięśnia czworogłowego. Cel. Zbadanie wpływu stymulacji magnetycznej na CSA mięśnia czworogłowego uda u pacjentów z chorobą zwyrodnieniową stawu kolanowego, a tym samym na czynność kolana. Materiały i metody. W niniejszym badaniu przyjęto schemat badań z randomizacją. W badaniu wzięło udział dwudziestu czterech pacjentów z chorobą zwyrodnieniową stawów kolanowych (stopień II i III). Uczestnicy w wieku 45–55 lat zostali losowo przydzieleni do dwóch grup. Grupa (A) była poddawana stymulacji magnetycznej oprócz wybranej fizykoterapii obejmującej terapię ultradźwiękową i ćwiczenia izometryczne na mięsień czworogłowy. Grupa (B) była poddawana wybranej fizjoterapii obejmującej terapię ultradźwiękową i ćwiczenia izometryczne na mięsień czworogłowy. Dwie sesje terapeutyczne odbywały się co tydzień przez trzy kolejne tygodnie. Miarami wyniku były CSA mięśnia czworogłowego po obu stronach i punktacja Lysholma do oceny sprawności funkcjonalnej stawu kolanowego. Pomiary wykonano przed i po trzech kolejnych tygodniach interwencji. Wyniki. W obrębie grup analiza wykazała istotny statystycznie wzrost dla wszystkich mierzonych zmiennych w obu badanych grupach ($p < 0,05$). Pomiędzy grupami analiza wykazała, że siła mięśnia czworogłowego uda po obu stronach i punktacja Lyshloma znacząco wzrosły w grupie (A) w porównaniu z grupą (B). Wnioski. Wprowadzenie SMS do ćwiczeń wzmacniających mięsień czworogłowy poprawiło CSA mięśnia czworogłowego, co chroni mięśnie przed zanikiem, a tym samym poprawia funkcje stawu kolanowego bardziej niż same ćwiczenia wzmacniające mięsień czworogłowy.

Słowa kluczowe

elektrostymulacja mięśni, choroba zwyrodnieniowa stawu kolanowego, mięsień czworogłowy uda, ćwiczenia wzmacniające

Introduction

Knee osteoarthritis (KOA) is a prevalent painful rheumatic disease, which causes swelling and physical disability, given the decreased strength of the lower extremity muscles. Sleep quality was poor in over half of our knee OA patients and best predicted by depression, pain and level of education. [1]. Although osteoarthritis refers to the reduced thickness or lost hyaline cartilage within the joint, functional disability may be caused by pathological muscle weakness. Also, muscle weakness and atrophy may exacerbate cartilage deterioration [2]. During clinical management of KOA, rehabilitation of the quadriceps muscular impairments should be considered, as KOA is not a disease of the cartilage only [3].

Muscle atrophy along with muscle inhibition will result in decreased generation of force in the quadriceps, indicating a failure of complete and volitional activation of the muscle [4]. The intensity of quadriceps, or peak torque production, is a key factor influencing the functional ability of KOA patients. The cross-sectional muscle area (CSA) as well as the ability of the nervous system to completely fire and recruit large motor muscle neurons are two determinants affecting the output potential of muscular force [5].

In the quadriceps muscle, arthrogenic muscle inhibition can occur as a sequence of knee joint dysfunction, so it can not be fully activated. Full muscle activation requires the recruitment of entire motor units at the maximum firing rate. Inability to achieve full activation of muscle fibres reveals a decrease in the rate of firing [6]. Patients with radiographic features of KOA exhibit a reduced CSA of quadriceps by 12% when compared to KOA cases that demonstrated no radiographic changes. However, they were similar in hamstrings CSA [7].

Arslan et al. [8] show that in patients with knee osteoarthritis, the use of 10-session neuromuscular electrical stimulation did not provide additional benefits for pain, physical performance, kinesiophobia, or quality of life. Therefore, when planning the treatment programme, the results should be considered.

Static magnetic stimulation (SMS) induces proliferation and identification on the skeletal muscle cell, like a magnetic flux density of 160–200 microT because it causes an increase in calcium ions. Since calcium ions are important for muscle contraction, which is the main function of the muscle, magnetic stimulation is considered a non-invasive preservation modality for the cross-section of the muscle [9].

Although the increase in intracellular calcium resulted from a significant decrease in its storage in sarcoplasmic reticulum cisternae, mature skeletal myotubes are capable of adapting to the effects of magnetic stimulation and maintaining their capacity for contraction. Subsequently, SMS can have a significant impact on muscle building [10].

Magnetic stimulation is beneficial for electrical stimulation, because when used to stimulate quadriceps, it generates less pain. It produces profound tissue penetration and recruitment of proprioceptive afferents with minimal activation of cutaneous nociceptors [11]. Magnetic stimulation, on the other hand, is less beneficial for focal stimulation of small muscles, as the majority of stimulators are too large to provide proper focused stimulation. SMS is therefore considered to stimulate deep and large muscles [12] as a modality. It is hypothesised that in knee osteoarthritis participants, there was no significant effect of SMS on quadriceps CSA.

Materials and Methods

This study was approved by the research ethics committee of Cairo University (P.T.REC/012/001). It was prospectively registered in the clinical trials registry (PACTR201805003383). Participation was voluntary. Each participant signed written informed consent prior to being enrolled in the study.

Participants

Studying 24 cases of knee osteoarthritis is considered an acceptable sample size based on the effect size retrieved from previous work in the medical literature. According to G-power analysis, the effect size for each group that consists of 12 patients is 0.90. All patients were enrolled in the outpatient clinic. The study was conducted from March to October 2019. The age of eligible participants ranged between 45 and 60 years because sarcopenia is most common in the 4th decade of life, with a reduction in both mass and function of skeletal muscles by 30–50%. It gets worse by the age of 80 years when muscles are unloaded in inactive elderly [13]. The body mass index (BMI) was 25-30 kg/m2; on recording the patient's history of the disease, reduced quality of life and physical function were reported by Lysholm knee scoring. Inclusion criteria included patient's age from 45-55 with both knee osteoarthritis (grade II and III) were involved according to Kellgren and Lawrence, with body mass index 25-30. Patients with cancer, advanced osteoarthritis, previous knee surgeries, and misaligned or lax knee were excluded from the study. A brief demonstration was given to all participants regarding the study and its procedures.

Randomization

A research assistant randomised a total of 24 patients with both knee osteoarthritis, opened closed casings enclosing automatically generated random cards through a study randomizer computer programme, and divided the participants into two identical groups. After randomization, the study did record one case dropout. In statistical analysis, an intent to treat analysis was used (Figure 1).

Intervention

Magnetic stimulation

Participants in Group A received magnetic first stimulation in addition to selected physical therapy consisting of ultrasound device and isometric exercise for quadriceps. Magnetic stimulation parameters were (intensity 2mT, and frequency 10 Hz), space plate electrodes were placed at muscle belly to increase the number of activated fibers, for 20 minutes at both sides. Sessions had been performed twice weekly for three consecutive weeks [14]. Medtronic Magpro R30 (Magventure, Lucernemarken, Denmark) with a coil 12 cm in diameter (MCF-125) was used. The maximum magnetic field output intensity was 3.1 Tesla per second, and the stimulation strength of was set to the maximum tolerable level for each participant. A 25-second resting phase was given between stimulations and a total of 1500 pulses were applied during each session.

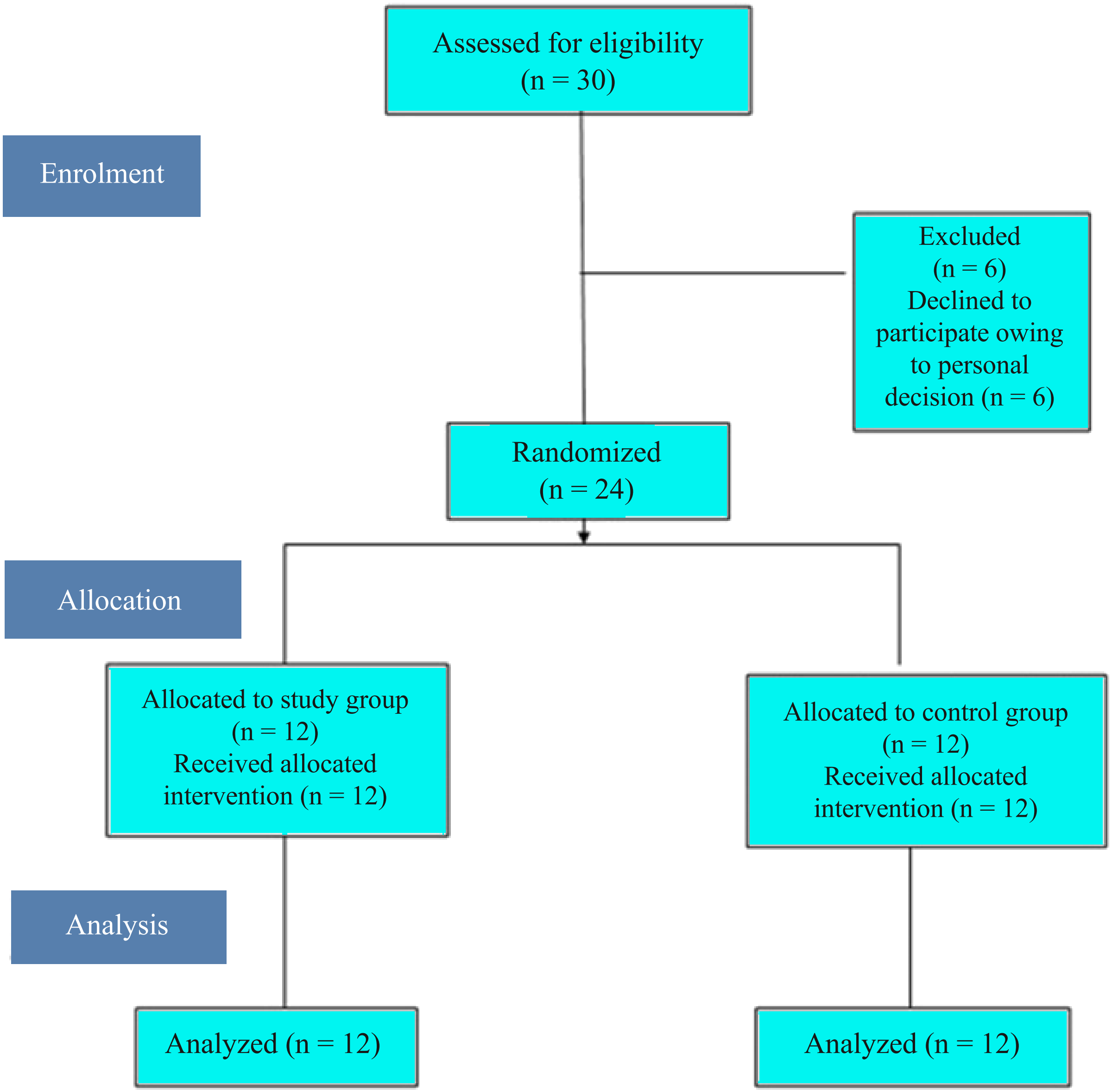

Figure 1. Flowchart showing the method of the study

Selected PT program

Ultrasound

Participants of both groups received a continuous ultrasound device (US), for 7 minutes, at the tender point around the both knee joints before the performance of the exercise. The parameters were 1.5 W / cmkw in intensity and 1 MHZ in frequency [15].

Quadriceps strengthening exercises

The quadriceps isometric exercise involved 1 set of 10 reps. Each set is repeated five times daily for both sides. Isometric exercises are low-cost and simple to perform, rapidly improve strength, and cause the minimum intra-articular inflammation, pressure, and bone damage [16].

Outcome measures

Quadriceps cross-sectional area at both sides and Lysholm knee scores were assessed pre-and post-intervention in both groups. US imaging is an alternative approach to CT and MRI for assessing muscle-wasting. US validity and reliability have been reported against CT for measuring CSA of the quadriceps muscle in both healthy and unhealthy people [17]. There is a correlation between quantitative ultrasonography and CT in measuring CSA and the composition of muscles [18].

Mode of ultrasound imaging was used to measure quadriceps CSA via an 8 Hz 5.6 cm linear transducer array (PLM805, Toshiba Medical Systems, Crawley, UK). The placement of the transducer was vertical to the thigh's longitudinal axis on its upper aspect, three-fifths of the distance from superior iliac spine to the base of the patella. ''participant's position was supine lying with supporting the rested leg in passive extension. The application of abundant conductive gel was made to minimize the distortion of underlying soft tissues. The operator was used to minimize oblique imaging via visual feedback to get the smallest cross-sectional image. The depth of scanning was set to where the femur could be detected for orientation. Maneuvers of gentle contraction-relaxation were performed to outline muscle septa before imaging acquisition [19].

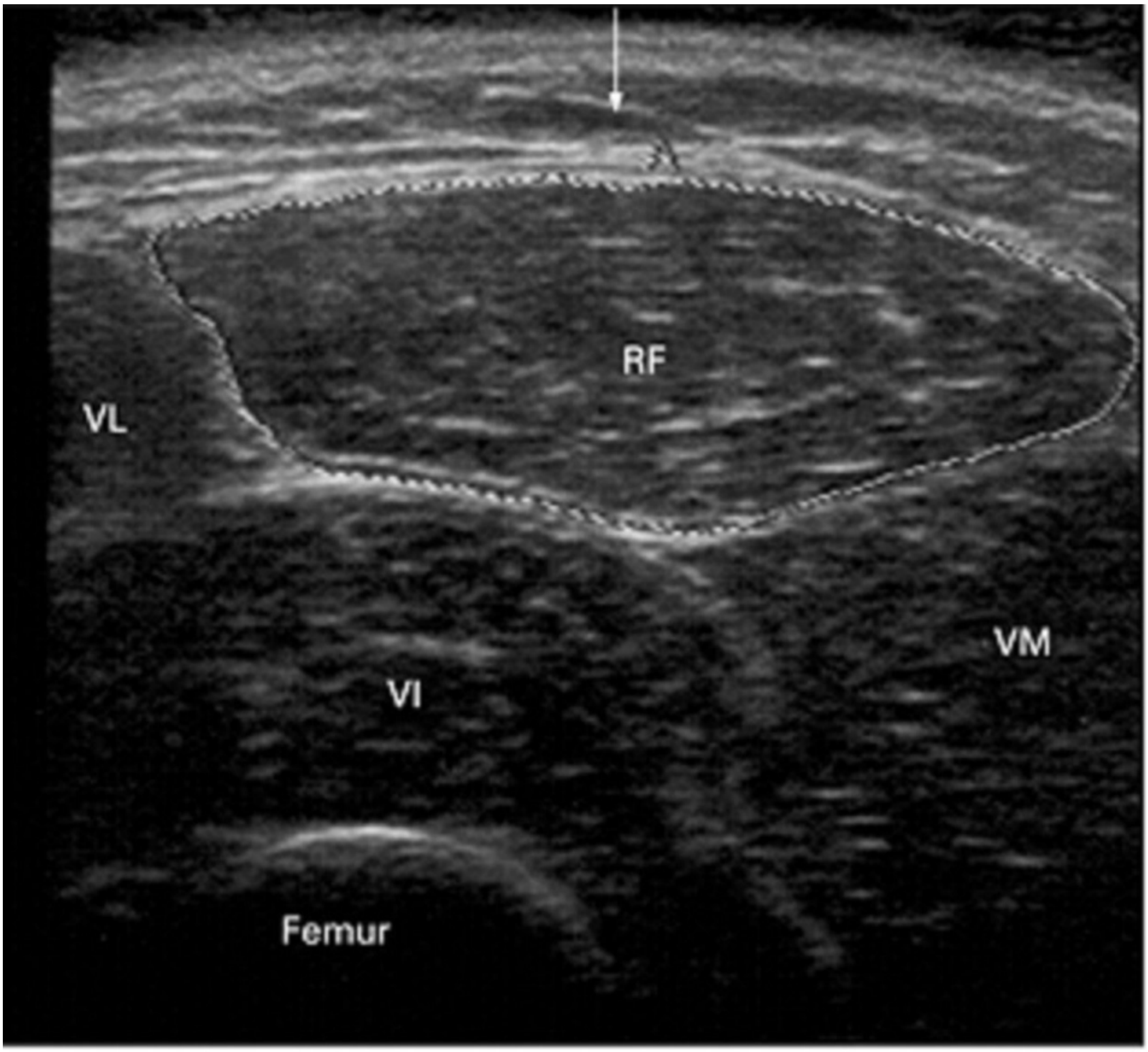

Figure 2. Ultrasound of the quadriceps

The Lysholm questionnaire
It was included as a disability outcome measure following ACL injury and reconstruction. The rating system of Lysholm questionnaire has been well established, as an alternative mechanism to gather outcomes data when evaluating knee injuries. The questionnaire has a total score of 100 points and consists of the following variables: Limping, crutch support, knee instability, knee locking, pain, swelling, knee function with stair climbing and knee function with squatting [20]. All participants in the both groups completed the questionnaire in two phases: pre-intervention (pretest) and three weeks' post-intervention (posttest). The total score of each subject pre and post-intervention was used for statistical analysis.

Statistical analysis
Data analysis was performed using Statistical Package for Social Sciences (SPSS) computer program (version 23 windows) (Charles R Flint, New York, USA.). Testing for the homogeneity of covariance showed that the difference was not significant as p values > 0.05. The normality test of data using the Shapiro-Wilk test revealed the data were normally distributed. So, parametric analysis was performed.
Potential differences in baseline characteristics between groups were tested by independent sample t-tests. A 2×2 mixed design MANOVA was used to examine the effect of treatment on the measured dependent variables (right quadriceps, left quadriceps, and Lyshlom rating scores) with the group as the between-subject variable (experimental received low frequency static magnetic stimulation in addition to selected physical therapy treatment consist of the US and isometric exercise for quadriceps, and the control group received only the traditional treatment(UD+ isometric exercise for quadriceps), and time as the within-subject variable (pre and post-treatment). The variable of interest was the group-by-time interaction at an a priori alpha level of 0.05 and 95% confidence interval.

Results
Twenty four subjects from both genders (14 females and 10 males) were screened for eligibility criteria in this study. There were non-significant differences between groups for demographic data (Table 1).

Table 1. Physical characteristics of subjects in studied groups

	Group [A] Mean ± SD	Group [B] Mean ± SD	t-test	p-value
Age [years]	58 ± 8.44	51.75 ± 6.91	1.948	0.065
Weight [kg]	79.5 ± 6.92	79.25 ± 6.87	0.089	0.93
Height [cm]	165.33 ± 3.89	164.5 ± 4.12	0.509	0.616
BMI [kg/m^2]	29.85 ± 2.72	29.25 ± 2.48	0.563	0.579

NS = P > 0.05 = non-significant, P = Probability

Multivariate tests for outcome measures indicate a statistically significant effects for group ($F = 23.032$, $p = 0.001$, Partial $\eta^2 = 0.865$), time ($F = 263.072$, $p = 0.001$, Partial $\eta^2 = 0.98$), and group-by-time interaction ($F = 102.118$, $p = 0.001$, Partial $\eta^2 = 0.96$). Within groups, the analysis showed a statistically significant increase for all measured variables in the two studied groups ($p < 0.05$). Between groups, the analysis revealed that quadriceps at both sides and Lyshlom were increasing in Group A more than B (Table 2).

Table 2. Baseline, post-intervention, within-group, and between-group differences and their associated 95% confidence intervals for outcome measures

	Right quadriceps		Left quadriceps		Lyshlom	
	Study group	Control group	Study group	Control group	Study group	Control group
Pre-treatment (Mean ± SD)	300.47 ± 7.03	305.45 ± 5.92	306.19 ± 6.66	311.05 ± 678	48.75 ± 21.08	41 ± 5.32
Post- treatment (Mean ± SD)	338.85 ± 4.29	312.23 ± 4.87	348.07 ± 3.76	318.78 ± 5.55	83.83 ± 16.61	52.58 ± 4.81
Within group change [mean (95% CI)]	−38.37 **(−41.851: −34.899)	−6.78 **(−10.259: −3.307)	−41.88** (−44.691: −39.076)	−7.73** (−10.541: −4.926)	−35.08 ** (−38.431: −31.736)	−11.58** (−14.931: −8.236)
Between groups difference for post-treatment [mean (95% CI)]	26.61 (22.725: 30.508)		29.29** (25.276: 33.308)		31.25 ** (20.892: 41.608)	

Discussion

Important increases in quadriceps CSA and progress in Lysholm knee scoring after SMS were seen in the current study. Maximum activation in the target muscle achieved in a non-invasive and painless manner, maximum activation in reverse to electrical stimulation, may give rise to painful sensation which may not allow sufficient stimulus application in some sensitive individuals to achieve the target[19].

In this study, significant improvements in quadriceps CSA at both sides were reported in the study group. This can be due to its effect on muscle enzymes, as it was found in the SMS study applied to the mouse model that there was only an increase in creatine kinase levels which, in the absence of other markers of rhabdomyolysis such as (alarmins and sMb), suggested that there was no substantial tissue damage to the muscle workout [21].

Knee osteoarthritis is generally associated with Quadriceps weakness, which typically results from atrophy of disuse as a sequence of pain and a reduction in mechanical load on the joint involved [22-28]. As the evidence of muscle growth leads to strength on the basis of two points: muscle size and contractile protein extraction to the targeted muscle, the results of our work improved in quadriceps.

This was in line with the results of the study of Western rats, a vitro model that showed that SMS has a stimulating effect on the proliferation and differentiation of skeletal muscle cells. The proliferation of dividing cells is dependent on intracellular calcium concentrations; exposure to myoblasts to SMS (160-200mT) causes calcium levels to increase in their cytosol, leading to a subsequent acceleration of cell division in addition to myotubic hypertrophy [2].

The results go hand in hand with previous studies that investigated the superiority of SMS over direct electrical stimulation in creating a small increase in the metabolites of creatine and minimising muscle damage [28]. By improving creatine kinase activity, inducing muscle fibres and histological changes in connective tissue, and delaying onset muscle soreness [29], electrical stimulation could cause muscle damage.

Similarly, our findings about the increase in the quality of life-related Lysholm knee scores after SMS are consistent with a previous study to investigate the impact of SMS on the reduction of post-traumatic muscle atrophy and the induction of hypertrophy of intact tissue muscle fibres, cross-sectional measurements were taken in both injured and intact areas. Compared to intact quadriceps myofibers, damaged myofibers without SMS have been reported to have a cross-sectional reduction of 38.56 percent. On the other hand, atrophy did not occur in SMS-stimulated muscles, with cross-sectional fibre measurements revealed to be greater than or equal to uninjured unstimulated control [30].

In addition, the recorded changes in the current study can account for the possibility of a regenerative process in atrophied muscles, as indicated by a substantial increase in central nucleus myotubes. In a model of mouse muscle crush injury, 80.7% ± 7.0 of treated muscle fibers by SMS revealed central nuclei, while only 41.5% ± 8.1 of untreated crushed muscle fibers showed regeneration [28-30]. These findings could be explained by myonuclear domain theory, which indicates that each myonucleus controls an area of surrounding cytoplasm and produces sufficient protein to support the limited area of cytoplasmic and structural proteins within the local "domain." Research has consistently reported myonuclear number increase in conditions of positive alterations in the size of fibers (e.g., muscle overload, hypertrophy, or growth) [31-32]. The overall findings of this study is consistent with the mainstream recommendation about using neuromuscular magnetic stimulation for strengthening the effect on the quadriceps and their cross-section to enhance neural excitability and improve the overall performance [33-38]. Isokinetic and isometric quadriceps muscle strength was measured using a Biodex system 4 (Biodex Medical Systems, Shirley, NY) was usually used to assess the muscular changes. Yang et al. [38] integrated US with neuromuscular magnetic stimulation to maximize the benefits. The primary limitation was the lack of follow up to examine the long-term effect of magnetic stimulation and recurrence of symptoms. Also, the study should be applied to participants who underwent knee surgery to evaluate the effect of magnetic stimulation.

Conclusion

The Quadriceps isometric exercise programme has benefit from the application of magnetic stimulation to enhance clinical results in cases of atrophied quadriceps recovery in patients with knee osteoarthritis. This integration helps to improve the quadriceps cross-section, and thus improves muscle efficiency more than quadriceps isometric exercise alone.

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