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The effect of quadriceps neuromuscular electrical stimulation on pain scores, functional tests and quality of life in military personnel with partial anterior cruciate ligament tears

El efecto de la estimulación eléctrica neuromuscular del cuádriceps en los puntajes de dolor, pruebas funcionales y calidad de vida en personal militar con desgarros parciales del ligamento cruzado anterior

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Data of the Article

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Abstract

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries. This study aimed to evaluate the effect of quadriceps neuromuscular electrical stimulation (NMES) on pain scores, functional tests, and quality of life in military personnel with partial ACL ruptures. A total of 60 male military patients with knee pain were divided into two groups: an intervention group receiving NMES and a control group without NMES. Both groups underwent standard treatments, including infrared therapy, ultrasound, and quadriceps strengthening exercises. Evaluations were performed before and after treatment for pain reduction (VAS scale), quality of life (QOL ACL questionnaire), and a 10-meter walk test. Data were analyzed using SPSS software. The mean VAS score in the NMES group decreased from 3.57 ± 1.25 to 1.07 ± 0.9, while in the control group it decreased from 3.6 ± 1.07 to 2.64 ± 1.66 ($P < 0.001$). The QOL scores improved from 32.08 ± 10.5 to 59.83 ± 6.9 in the NMES group and from 31.03 ± 9.8 to 41.6 ± 7.1 in the control group ($P < 0.001$). No statistically significant difference was observed in the 10-meter walking test between the groups. Quadriceps NMES appears to be a promising intervention for reducing pain, improving muscle function, and enhancing the quality of life in patients with partial ACL ruptures.

Resumen

La ruptura del ligamento cruzado anterior (LCA) es una de las lesiones de rodilla más comunes. Este estudio tuvo como objetivo evaluar el efecto de la estimulación eléctrica neuromuscular (NMES) del cuádriceps en los puntajes de dolor, pruebas funcionales y calidad de vida en el personal militar con rupturas parciales del LCA. Un total de 60 pacientes militares masculinos con dolor de rodilla se dividieron en dos grupos: un grupo de intervención que recibió NMES y un grupo de control que no lo recibió. Ambos grupos se sometieron a tratamientos estándar, incluidos terapia infrarroja, ultrasonido y ejercicios de fortalecimiento de cuádriceps. Las evaluaciones se realizaron antes y después del tratamiento para la reducción del dolor (escala VAS), calidad de vida (cuestionario QOL ACL) y prueba de caminata de 10 metros. Los datos se analizaron utilizando el software SPSS. El puntaje promedio de VAS en el grupo NMES disminuyó de 3.57 ± 1.25 a 1.07 ± 0.9, mientras que en el grupo de control disminuyó de 3.6 ± 1.07 a 2.64 ± 1.66 ($P < 0.001$). Los puntajes de calidad de vida (QOL) mejoraron de 32.08 ± 10.5 a 59.83 ± 6.9 en el grupo NMES y de 31.03 ± 9.8 a 41.6 ± 7.1 en el grupo de control ($P < 0.001$). No se observó una diferencia estadísticamente significativa en la prueba de caminata de 10 metros entre los grupos.

Introduction

The stability and function of the knee joint rely heavily on two primary ligaments: the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL), both of which play a critical role in joint kinematics[1,2]. While PCL injuries are less frequent, ACL injuries particularly partial or complete ruptures are among the most common and debilitating knee injuries in physically active populations, including military personnel[3-5]. These injuries often result from sudden deceleration, twisting motions, or direct trauma, and they significantly impact patients' ability to perform daily activities, especially those involving walking, running, or changes in direction[6,7].

ACL rupture has a high global prevalence, with between 100000 to 200000 reconstruction procedures performed annually in the United States alone[8]. The increasing incidence among young and physically active individuals, especially female athletes, highlights the importance of early diagnosis and appropriate intervention[9-11]. Symptoms of ACL injury whether partial or complete include knee pain, swelling, instability, and limited range of motion, and they can be associated with additional damage to the menisci, articular cartilage, or other supporting ligaments[12-14]. These injuries may also cause long-term complications such as osteoarthritis, especially if not treated properly[15].

The psychological effects of ACL injuries further reduce patients' quality of life, as fear of re-injury and decreased confidence may prevent full return to physical activity[14]. Accurate diagnosis of ACL rupture is based on clinical assessment and imaging tools, including the Lachman test, anterior drawer test, pivot shift test, and magnetic resonance imaging (MRI), which together ensure a correct classification of injury severity[16,17]. Proper diagnosis is crucial to guide the selection between surgical and non-surgical treatment strategies[17].

Treatment approaches for ACL rupture include both operative and non-operative methods, and recent advances have refined these strategies to target optimal outcomes[18,19]. While anatomical reconstruction is the gold standard for complete ruptures, non-surgical management of partial ACL injuries may be viable when supported by structured rehabilitation[20,21]. Rehabilitation protocols typically follow a phase-based progression, beginning with the reduction of swelling and pain, followed by neuromuscular and perturbation training to enhance joint stability[22,23]. Final rehabilitation phases focus on muscle strengthening and psychological readiness for return to sport or duty[19,24].

The choice between surgical and non-surgical treatment depends on individual factors such as the extent of injury, functional instability, and patient goals. In both approaches, restoring quadriceps muscle strength is a key goal, as its weakness correlates strongly with poor functional outcomes and prolonged recovery[25,26]. The quadriceps are particularly vulnerable to atrophy following ACL injury and surgery, with significant decreases in strength during the first 4-12 postoperative weeks due to biological changes in graft remodeling and neuromuscular inhibition[26,27].

Neuromuscular electrical stimulation (NMES) has emerged as a promising adjunct to conventional rehabilitation for maintaining or improving quadriceps muscle function. NMES promotes muscle activation through electrical impulses, helping to counteract disuse atrophy and enhance neuromuscular control. Studies have shown its effectiveness in improving muscle fiber size, strength, and function when applied in the early postoperative period or during conservative management[28]. Additionally, NMES may

reduce inflammatory markers and support joint health when integrated with physical exercise, such as plyometric or Pilates training[29,30].

Despite the documented potential of NMES, limited evidence exists regarding its specific application in military personnel with partial ACL ruptures a population characterized by high physical demands and a need for efficient recovery strategies. Understanding the impact of NMES on pain reduction, functional performance, and quality of life in this group is critical for developing more effective rehabilitation protocols.

Therefore, the aim of this study was to evaluate the effect of quadriceps neuromuscular electrical stimulation (NMES) on pain levels, walking performance, and quality of life in military personnel with partial ACL ruptures, comparing outcomes between an intervention group receiving NMES and a control group receiving standard care.

Materials and methods

This study was conducted as a single-blind, interventional clinical trial in 2023. The study population consisted of male military-operational personnel who presented with a diagnosis of partial ACL rupture at the Physical Medicine and Rehabilitation Clinic of Baqiyatullah Hospital, Tehran.

Sample size and randomization. The required sample size was calculated using the standard formula for clinical trials, resulting in 56 participants. To account for possible dropout, 60 individuals were enrolled. Participants were randomly assigned to two groups (intervention and control), each comprising 30 subjects. Randomization was performed using a block randomization method with a block size of four to ensure equal distribution across groups.

Inclusion criteria. Patients eligible for inclusion were males aged 20-45 years, diagnosed with a partial ACL tear confirmed via MRI or clinical examination by a specialist physician. All participants had no history of ACL surgery or neurological disorders and provided informed consent before inclusion.

Intervention protocol. All participants received standard physiotherapy care; however, only the intervention group received quadriceps NMES in addition to standard care.

Group A (intervention group). Participants received the following interventions for 10 sessions over 5 weeks (2 sessions per week): i) Was applied to the quadriceps using a biphasic symmetrical rectangular pulse waveform with a phase duration of 300 μs, a frequency of 30 Hz, and a maximum intensity of 100 mA. Electrodes were placed over the vastus medialis and lateralis for 20 min per session. The NMES protocol followed established recommendations for ACL rehabilitation and muscle re-education[31,32]. ii) Infrared therapy (IR): was applied to the knee for 10 min per session to reduce inflammation and pain and enhance local circulation. This technique is supported for use in musculoskeletal disorders and knee rehabilitation[33]. iii) Ultrasound therapy (US): Pulsed ultrasound (5 min/session) was applied to the anteromedial and anterolateral aspects of the knee. Therapeutic ultrasound is known to promote tissue healing and reduce joint stiffness in ACL-related injuries[33]. iv) Quadriceps and lower limb strengthening exercises: a) Quadriceps exercises: Supine straight leg raises (SLR), static quadriceps setting, and open-arc exercises with a 1 kg weight, performed in 3 sets of 20 repetitions (10-s contraction each). b) Hip abductor strengthening: Side-lying SLR with a 1 kg weight, 3 sets of 20 repetitions (10-s contraction). c) Hip extensor strengthening: Prone SLR (without lumbar extension), 3 sets of 20 repetitions with a 1 kg weight (10-s contraction). d) Hamstring curls: Standing knee flexion to 90°, using a 1 kg weight, 3 sets of 30 repetitions. These exercises were chosen based on exist-

ing rehabilitation protocols for ACL injuries and are proven to enhance muscle strength, joint control, and knee function[31,32].

Group B (control group). Participants in the control group received standard physiotherapy, including. i) I: 10 min per session on the knee. ii) Ultrasound therapy (US): 5 min per session on the inner-anterior and outer-anterior regions of the knee. iii) No NMES was applied in this group.

Outcome measures. All participants underwent pre- and post-treatment assessments using the following tools. i) Pain intensity: Measured using the Visual Analogue Scale (VAS), a validated and widely used instrument for pain assessment. ii) Quality of life: Evaluated using the ACL-specific quality of life questionnaire (QOL-ACL), which assesses physical and psychosocial functioning. iii) Functional performance: Measured using the 10-m walk test to evaluate walking speed and gait efficiency.

Statistical analysis. Data were analyzed using SPSS software version 26. Descriptive statistics were used to summarize the data. Between-group comparisons were conducted using the independent samples t-test. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 60 male patients were included in the study, and 30 people were evaluated equally in each group. The average age of the patients was 33.22±5.26 years and the body mass index was 24.89±3.21. At the beginning of the study, the average VAS was 3.57±1.25 and 3.6±1.07 for the groups with electrical nerve stimulation and without electrical nerve stimulation (Table 1). Also, the average of the 10-m walking test was 8.42±0.89 and 8.48±1.8 seconds for the groups with electrical nerve stimulation and without electrical nerve stimulation. On the other hand, the average QOL ACL questionnaire for the groups with nerve electrical stimulation and without nerve electrical stimulation was 32.08±10.5 and

Table 1 Clinical characteristics of the participants at the beginning of the study (number = 60)

Variables	Electrical nerve stimulation (number = 30)	without electrical nerve stimulation (number = 30)
Gender	Man	Man
Age (years), mean + standard deviation	33.63±5.00	32.8±5.54
body mass index (kg m^{-2})	25.7±2.7	24.09±3.6
VAS	3.57±1.25	3.6±1.07
ACL QOL	32.08±10.5	31.03±9.8
10-meter walk test (seconds)	84±.89	8.48±1.8

Table 2 Treatment results of patients after 5 weeks of intervention

Variables		Electrical nerve stimulation (number = 30)	without electrical nerve stimulation (number = 30)	P-Value
Age (years), mean + standard deviation		33.63±5.00	32.8±5.54	.54
body mass index (kg m^{-2})		25.7±2.7	24.09±3.6	.051
VAS	Before	3.57±1.25	3.6±1.07	.91
	After	1.07±.9	2.64±1.66	<.001
VAS	Before	32.08±10.5	31.03±9.8	.242
	After	59.83±6.9	41.6±7.1	<.001
10-meter walk test (seconds)	Before	84±.89	8.48±1.8	.88
	After	6.98±1.57	7.46±.05	.78

All subjects were treated for 10 sessions (5 weeks). None of the patients had swelling, effusion or infection after knee intervention. A significant difference was observed for the VAS score and QOL ACL between the two groups in 5 weeks after the intervention (P>0.05) and the variable of walking time of the 10-meter path in terms of statistical analysis did not have a statistically significant difference between the two groups (P<0.05). Figure 1-3. Also, other demographic information (age and body mass index) had no statistically significant difference between the two groups.

Figure 1 The average of the 10-meter walking test (seconds) before and after the intervention

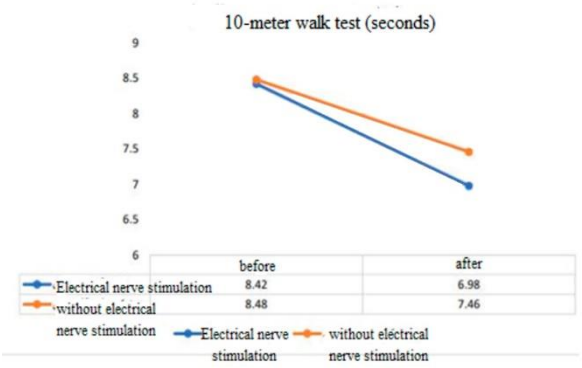
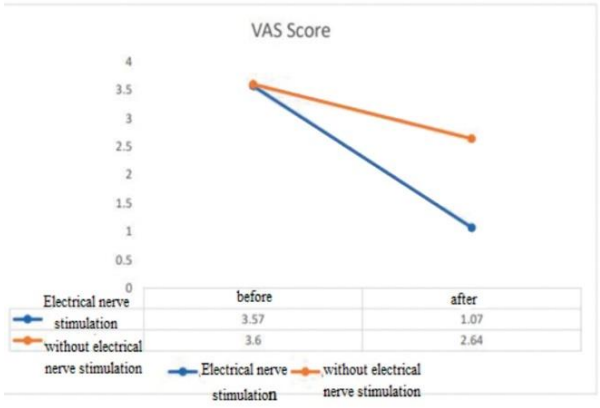


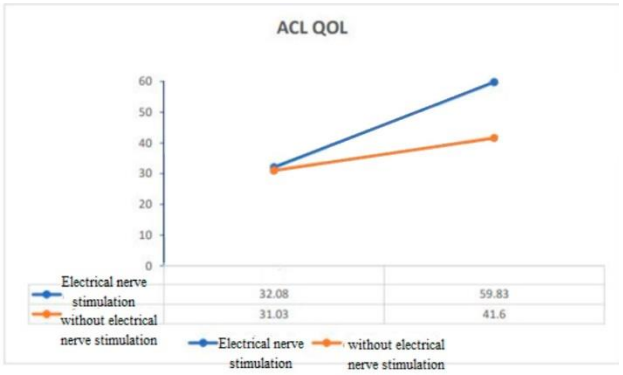
Figure 2 Average VAS score before and after the intervention



Discussion

This study examined the impact of quadriceps NMES on pain, functional performance, and quality of life in military personnel with partial ACL tears. The intervention group that received NMES in addition to standard rehabilitation protocols showed improvements in both pain reduction and ACL-specific quality of life after five weeks, compared to the control group that received only conventional treatment.

Figure 3 Average QOL of ACL before and after the intervention



These results support previous findings by Toth et al.[33], who demonstrated that early application of NMES after ACL injury preserved quadriceps muscle size and fiber contractility, particularly type I and type II fibers, and reduced muscle atrophy in patients undergoing ACL reconstruction. While Toth et al.[33] study focused on cellular and structural muscle responses over three weeks, our study confirms that such benefits may extend into functional domains like pain perception and daily performance when NMES is integrated into a longer, five-week clinical rehabilitation protocol.

In contrast to the NMES-centered approach, Chmielewski et al.[34] investigated low-versus high-intensity plyometric exercises after ACL reconstruction. While no significant differences were reported

between exercise intensities in terms of physical outcomes, both groups demonstrated reductions in cartilage degeneration markers[33]. Our study adds to this body of knowledge by showing that the inclusion of NMES alongside exercise therapy may further enhance patient-reported outcomes, such as quality of life and pain relief, compared to standard training protocols alone.

Supporting the importance of quadriceps-focused rehabilitation, Tagesson et al.[35] found that both open-chain and closed-chain strengthening exercises improved tibial control and knee function in patients with ACL injuries[17]. Our intervention combined quadriceps exercises in multiple planes with NMES, suggesting that pairing strength protocols with neuromuscular reactivation technologies may accelerate functional gains and improve subjective outcomes. However, unlike Tagesson et al.[35] study, which emphasized tibial motion, our outcome measures focused on patient-centered indicators, including the VAS and ACL-QOL scores.

The effectiveness of non-traditional exercise methods was also seen Çelik et al.[36], who investigated Pilates training for patients with partial ACL ruptures. Their results indicated significant improvements in muscle balance and symptom relief through low-impact neuromotor control exercises[30]. Our findings similarly support conservative treatment options for partial ACL injuries, particularly when NMES is used to facilitate early quadriceps activation and performance.

Despite the promising results, the present study has limitations. First, it employed a single-blind design, unlike the double-blind method used by Toth et al.[33]. Second, our outcome assessments did not include muscle histology, inflammatory biomarkers, or imaging follow-up, which could further clarify the biological impact of NMES. Finally, while five weeks was sufficient to observe short-term improvements, long-term durability of these effects remains unclear.

In conclusion, the integration of quadriceps NMES into a structured rehabilitation protocol for military personnel with partial ACL tears appears to significantly reduce pain and enhance quality of life. These outcomes suggest that NMES is a promising non-surgical adjunct to standard physiotherapy, particularly for patients in high-demand environments such as the military. Given the functional importance of the quadriceps and the risk of chronic knee instability, future research should explore long-term outcomes of NMES, evaluate its cost-effectiveness, and investigate whether it can reduce the need for surgical intervention. Additionally, studies should include biological and psychological outcome measures to provide a more comprehensive view of its rehabilitation benefits.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Ethical considerations

The study guaranteed respect for the privacy and confidentiality of the information obtained.

Research limitations

This study was limited by its short follow-up period, single-center design, and absence of imaging or biochemical outcome measures to evaluate deeper physiological changes.

Authors' contributions

All authors contributed equally to the conceptualization, field investigations, stratigraphic analysis, data interpretation, manuscript writing, and final approval of the article.

Data availability

The data supporting the findings of this study are not publicly available due to their technical specificity and field-sensitive nature, but they are available from the corresponding author upon reasonable academic request and for non-commercial research purposes.

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No generative artificial intelligence tools were used in the writing of this manuscript. All content was produced by the authors.

Image generation disclosure

All figures, illustrations, and diagrams in this article were generated by the authors using standard software. No AI-based tools were used for image creation.

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