

## ORIGINAL SCIENTIFIC PAPER

# The Effects of the Comprehensive Rehabilitation Method on Quadriceps Activation: Outcomes in Patients with an Injury to the Anterior Cruciate Ligament

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## Abstract

Dynamics of the indices of interferential superficial electromyography of the quadriceps muscle in patients with an injury to the anterior cruciate ligament (ACL) of the knee joint were investigated in the process of physical rehabilitation. The study included 39 randomly selected individuals with a complete ACL tear who were qualified for surgical reconstruction. The age of the participants was 18–59 (average:  $36.3 \pm 12.8$ ) years. All participants underwent rehabilitation treatment in the Institute of Traumatology and Orthopaedics, National Academy of Medical Sciences of Ukraine, and had surgeries in the institute's clinics. In the functional rehabilitation period, in patients in the main group, who were engaged in the author's programme, there were no statistically significant differences in the mean amplitude of the quadriceps head intact and injured limbs ( $p > 0.05$ ). The values of the comparative factor of maximal contraction of the heads of the quadriceps muscle of the intact and injured limbs of the patients approached the norm. In patients in the control group, a statistically significant ( $p < 0.05$ ) difference in the mean values of the mean amplitude of the contraction of the heads of the quadriceps muscle of the injured and intact limbs was established: in relation to vastus medialis –  $98.93 \pm 37.13$  mV and  $175.90 \pm 65.96$  mV, in relation to the rectus femoris muscle –  $113.59 \pm 62.67$  mV and  $169.99 \pm 52.23$  mV.

**Keywords:** physical rehabilitation, trauma, anterior cruciate ligament, knee joint, recovery treatment

## Introduction

A total of 20% of all sports-related knee injuries are ruptures of the anterior cruciate ligament (ACL), which is evidenced by more than 100,000 cases annually in the United States. ACL rupture often leads to knee joint instability during daily activities. To compensate for the knee instability, ACL-deficient (ACLD) patients adopt an asymmetrical gait pattern, consisting of altered knee joint movement, moment, and contact forces. However, muscle timing and the magnitude of activity are of great importance (Shanbehzadeh, Mohseni,

Bandpei, & Ehsani, 2017).

Electromyography (EMG) is widely used in sports medicine for investigating potential alterations in the muscle activation patterns in pathologic conditions in order to facilitate the development of evidence-based training and rehabilitation programmes (Kvist, & Gillquist, 2001; Knoll, Kocsis, & Kiss, 2004; Shanbehzadeh, Mohseni, Bandpei, & Ehsani, 2017). Recently, increasing research results suggest that altered quadriceps and hamstrings activation in ACL injury may only exist in the presence of knee instability as part of an adaptation



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strategy to support joint stability, that is, inhibited quadriceps activity with concurrent increased activity of both quadriceps and hamstrings (Begalle, Distefano, Blackburn, & Padua, 2012; de Jong, Caspel, & Haeff, 2007). It has been reported that disproportionate activity of the quadriceps and hamstring muscles results in muscle imbalance and increased strain in the ACL (Begalle, Distefano, Blackburn, & Padua, 2012; Hewett, Zazulak, Myer, & Ford, 2005). Hence, many ACL injury prevention and rehabilitation programmes attempt to reinstate quadriceps-hamstrings activation balance (Pappas, Nightingale, & Simic, 2015; Khaiyat & Norris, 2018).

This study is aimed at investigation of the effects of the comprehensive rehabilitation method on quadriceps activation in patients with an injury to the anterior cruciate ligament.

## Methods

### Participants

The study included 39 randomly selected individuals with a complete ACL tear who were qualified for surgical reconstruction. The age of the participants was 18–59 (average:  $36.3 \pm 12.8$ ) years. Among the exclusion criteria, there were partial ruptures of the ACL, combined injuries of the ACL and meniscus, and ACL and cartilage damage, identified by ultrasound and magnetic resonance imaging (MRI). In the process of the research, we systematized and consolidated data from 39 medical records of patients treated in the Institute of Traumatology and Orthopaedics, National Academy of Medical Sciences of Ukraine from 2016 to 2018 and were operated on in the hospitals of the Institute. The femoral end of the transplant was fixed with the help of the RigidFix or Cross-Pin systems, and the tibial end by using the Biointrafix or Biosure Sync systems. The patients, without temporary contraindications for arthroscopic operative intervention, were examined by using instrumental methods of research. The examination was performed within different periods of recovery treatment. Overall, 21 participants (the main group) underwent rehabilitation in accordance with the proposed programme after ACL reconstruction; in 18 patients (control group), the traditional programme of physical rehabilitation was implemented. The results registered at the preliminary stage of the research showed no statistically significant differences between the examined indicators and the age of the patients among the control group and the main group.

### Procedure

To achieve the set target in this study, the following methods were used: theoretical analysis of data from the scientific and methodological literature; pedagogical; clinical (examination, anamnesis collection); instrumental methods of research (anthropometric measurements, goniometry, electromyography); and methods of mathematical data processing.

The algorithm of the complex diagnostics for acute ACL injuries, created at the institute, was applied to the patients having corresponding claims; the algorithm implied clinical, functional, X-ray, ultrasound, and MRI examination. In all the hospitalized patients, the following procedures were applied: definition of the patient's claims, anamnesis; clinical examination, palpation; examination of the injured joint function, evaluation of instability level, presence of block, synovitis, infiltration, muscular atrophy, X-ray, ultrasound, MRI (if possible) examination of the knee joint, and similar. The obtained

data were recorded in the patients' medical history. During the clinical examination and anamnesis collection, all participants were asked about the reason for visiting the rehabilitation department; the intensity of pain syndrome (the Visual Analogue Scale of pain was applied); their claims on pain syndrome during active movements, passive movements, and at rest; instability of knee joint; quantitative measurements of instability were performed in accordance with the criteria of the American Association of Arthroscopy.

The research related to human use has complied with all the relevant national regulations and institutional policies; has followed the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or an equivalent committee.

Informed consent has been obtained from all individuals included in this study.

### Statistical analysis

The following methods of mathematical statistics were applied: descriptive statistics, selective method, Shapiro-Wilk's normality test, Student's t-test, non-parametric Mann-Whitney test, and factor analysis. Methods of descriptive analysis were used, including tabular presentation of separate variables, calculation of mean arithmetic value (M), standard deviation (SD). The sample data for normality were tested with the normal distribution formula and the Shapiro-Wilks test. To determine the statistical significance of the differences between the samples of normal distribution, the Student's test was used. The level of  $p \leq 0.05$  (the probability of error) was assumed statistically significant.

## Results

Thus, the analysis of results in the research of the specific limb functional conditions among the examined patients with knee joint ACL injuries allowed outlining the main set of tasks that should be solved in the process of rehabilitation programme development. Having studied the specifics of the lower limb functional conditions among the participants, we described and developed a physical rehabilitation programme for patients after ACL reconstruction with arthroscopic operative interventions. The programme consisted of five periods: preoperative, early postoperative, late postoperative, functional periods, and a period of higher physical activity. The basis of the programme was the use of workout modules on the Gamma Platform, remedial gymnastics, and massage with elements of passive workout to increase the movement amplitude in the injured joint and post-isometric relaxation, mechanotherapy on a joint workout machine, and keeping to the orthopaedic routine. The specific feature of the developed programme of physical rehabilitation for patients with injured ACL, comparing with the traditional programme, was, mainly (except the early postoperative rehabilitation period) the use of the workout modules "Boat", "Ball swing", "Sorting balls", "Trampoline jumping", "Jump rope", and "Combined" on the Gamma Platform, which enhanced the elimination of loading asymmetry between intact and injured limbs and the faster recovery of the functional abilities of the operated joint.

To assess the effectiveness of the rehabilitation programme, two groups of patients were formed: the main group, who followed the presented authors' programme ( $n=21$ ), and the control group ( $n=18$ ), of patients who underwent the recovery treatment course including remedial gymnastics, classical

**Table 1.** Dynamics of indices of interferential superficial electromyography of maximal contraction of the rectus femoris muscle and of vastus medialis of the quadriceps muscle in patients of the main group (MG=21) and control group (CG=18) with damage to the anterior cruciate ligament of the knee during recovery

The studied indicators	Limbs	The preoperative rehabilitation period			The early postoperative rehabilitation period			The late postoperative rehabilitation period			The functional rehabilitation period		
		MG		P	CG		P	MG		P	CG		P
		M±SD	M±SD		M±SD	M±SD		M±SD	M±SD				
Amplitude of vastus medialis (mV)	injured	114.81±27.97	107.59±18.64	p>0.05	69.23±14.18	67.03±13.73	p>0.05	230.83±36.89	108.50±39.44	p≤0.05*	306.93±71.24	98.93±37.13	p≤0.05*
	intact	143.54±47.21	137.71±31.95	p>0.05	160.53±24.11	160.56±25.09	p>0.05	253.93±59.03	164.42±24.82	p≤0.05*	299.16±118.43	175.90±65.96	p≤0.05*
p		p≤0.05*	p≤0.05*		p≤0.05*	p≤0.05*		p≤0.05*	p≤0.05*		p>0.05	p≤0.05*	
Median frequency of vastus medialis, (Hz)	injured	62.16±32.09	51.80±43.09	p>0.05	43.33±16.82	43.57±16.08	p>0.05	93.47±19.71	59.44±15.99	p≤0.05*	117.57±30.08	51.41±29.72	p≤0.05*
	intact	70.47±30.19	70.07±31.42	p>0.05	77.60±30.90	77.23±32.29	p>0.05	135.50±46.43	74.96±19.31	p≤0.05*	123.13±40.57	106.10±32.66	p>0.05
p		p>0.05	p>0.05		p≤0.05*	p≤0.05*		p≤0.05*	p≤0.05*		p>0.05	p≤0.05*	
Amplitude of the rectus femoris muscle, (mV)	injured	115.42±24.38	109.68±36.15	p>0.05	90.36±22.63	92.11±24.60	p>0.05	187.81±61.13	117.70±26.01	p≤0.05*	300.95±93.27	113.59±62.67	p≤0.05*
	intact	157.09±33.05	148.85±44.60	p>0.05	196.81±54.79	200.62±60.58	p>0.05	217.21±69.18	142.47±34.79	p≤0.05*	313.42±98.60	169.99±52.23	p≤0.05*
p		p>0.05	p>0.05		p>0.05	p>0.05		p>0.05	p>0.05		p>0.05	p≤0.05*	
Median frequency of the rectus femoris muscle, (Hz)	injured	60.64±19.10	52.73±29.25	p>0.05	54.98±20.06	59.73±17.09	p>0.05	116.40±12.03	65.42±21.48	p>0.05	121.77±11.46	68.13±32.69	p>0.05
	intact	54.13±13.57	56.70±12.70	p>0.05	77.35±29.70	83.86±26.30	p>0.05	73.60±16.40	81.50±22.15	p>0.05	127.20±28.50	108.01±18.08	p>0.05
p		p>0.05	p>0.05		p>0.05	p>0.05		p>0.05	p>0.05		p>0.05	p≤0.05*	

Legend: \* - p≤0.0

massage and physical therapy methods in accordance with the hospital programme. The study of the results, their comparison with the baseline data (registered during the preoperative period, 1–4 weeks before the surgical intervention) and their evaluation were performed before the discharge from the hospital, during the early postoperative period (up to 2 weeks after the surgical intervention), during the late postoperative period (3–16 weeks after the surgical intervention), and in the functional period (17–32 weeks after the surgical intervention) of the recovery treatment.

Following the results of superficial electromyography examination, the estimation of the bioelectrical activity of the rectus femoris muscle and among patients with ACL of knee joint injuries was provided (Table 1). The baseline average indices of superficial electromyography examination amplitude of the rectus femoris muscle (mV) of the injured limb were patients of the main group (MG) –  $114.81 \pm 27.97$  mV ( $M \pm SD$ ) and the control group (CG) patients –  $107.59 \pm 18.64$  mV ( $M \pm SD$ ), the amplitude of vastus medialis, (mV) of the injured limb – patients of MG –  $115.42 \pm 24.38$  mV ( $M \pm SD$ ) and patients of CG –  $109.68 \pm 36.15$  mV ( $M \pm SD$ ). The indicators for the studied parameters among the patients of the groups (CG and MG) did not present statistically significant differences ( $p > 0.05$ ).

In the late postoperative period in patients with MG and CG, the average indicators of interferential superficial electromyography of amplitudes of the rectus femoris muscle and of vastus medialis of the injured limb significantly improved and amounted to patients of MG –  $230.83 \pm 36.89$  mV ( $M \pm SD$ ) and  $187.81 \pm 61.13$  mV ( $M \pm SD$ ), CG –  $108.50 \pm 39.44$  mV ( $M \pm SD$ ) and  $117.70 \pm 26.01$  mV ( $M \pm SD$ ). The indicators for the studied parameters among the patients of the groups (CG and MG) did present statistically significant differences ( $p < 0.05$ ).

Thus, in the functional rehabilitation period, in patients with MG, who were engaged in the author's programme, there were no statistically significant differences in the mean amplitude of the quadriceps head intact and injured limbs with statistically significant difference ( $p > 0.05$ ).

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There are no acknowledgements.

#### Conflict of Interest

The authors declare that there is no conflict of interest.

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#### Discussion

The research performed by Shanbehzadeh, Mohseni, Bandpei, and Ehsani (2017) proves the positive impact of the increased hamstring muscular activity, while simultaneously highlighting the important fact that at the acute stage and in ACLD patients that experience knee instability there is a decreased Q-ceps activation, which provides a better picture of the rehabilitation treatment process and suggests considering such finding when working on the rehabilitation strategy.

Another study, performed by Suter, Herzog, and Bray (2001) to assess muscle inhibition in patients with chronic anterior cruciate ligament (ACL) deficiency or ACL reconstruction, provided a picture of the application of a series of protocols when striving to increase the activity of the individual knee extensor muscles and decreasing muscle inhibition of the whole quadriceps group.

An additional critical study, by Drechsler and Oona (2007), provided an analysis of the process of neuromuscular changes in the quadriceps femoris muscle at one and three months after anterior cruciate ligament reconstruction (ACLR). The results of this study once again confirmed our thesis that muscle activation patterns may be altered not only following ACL injury and surgical repair but also may contribute to subsequent changes in muscle fibre properties during detraining and subsequent retraining.

The conducted studies of the effectiveness of the developed complex programme of physical rehabilitation confirm the data on its significant advantage in comparison with the traditional programme of the medical institution.

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