MEDICAL REHABILITATION OF HIGH PERFORMANCE ATHLETES AFTER RECONSTRUCTION OF ANTERIOR CRUCIATE LIGAMENT OF THE KNEE

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The professional activity of high performance, or elite sportsmen involves loads approaching extreme exertion, which often leads to injuries of the lower limbs. Anterior cruciate ligament (ACL) injury is one of the most common types of knee injuries. This study aimed to evaluate the effectiveness of a comprehensive rehabilitation program for athletes that underwent arthroscopic ACL reconstruction. The study involved 64 athletes aged from 17 to 31 years. Treatment group participants were offered a comprehensive medical rehabilitation program that included isokinetic training sessions on the TECNOBODY IsoMove biomechanical exercising machine; the sessions followed a purpose-designed method. The results of medical rehabilitation of the athletes were assessed through gait analysis done with a DIERS Motion 4D complex. The assessments took place 8 and 15 weeks after the reconstruction. At 8 weeks after the surgery, gait analysis parameters revealed no significant differences between the groups. Fifteen weeks after the reconstruction, when treatment group (TG) members were through all the isokinetic training sessions, the results were as follows: for the Stand Time parameter, the operated limb (OL) support deficit was 0.04% compared to the healthy limb (HL) support, and for the Single Limb Support parameter it was 3.71%, while in the control group (CG) that had no isokinetic training sessions the values were 12.44% and 18.55%, respectively. As for the Swing Time parameter, TG participants showed the deficit of HL transfer symmetry (relative to OL) of 3.99%, while the value of this parameter in the CG was 20.54%. The difference is significant, which proves the effectiveness of the developed isokinetic training method as part of the comprehensive medical rehabilitation program, the application of which resulted in faster recovery of muscle strength and compromised walking-associated support and locomotor functions in TG athletes.

Keywords: ACL, arthroscopy, rehabilitation, isokinetic training, gait analysis, highly trained athletes

Author contribution: R.A. Boichenko — literature review, data collection, data analysis, text authoring, determination of gait comparison parameters, statistical data processing; S.V. Gornov — study design development, editing and approval of the final version of the article.

Compliance with ethical standards: the study was approved by the Ethics Committee of the Federal Research and Clinical Center for Sports Medicine and Rehabilitation of the Federal Medical Biological Agency (Minutes of Meeting #01-09 of September 15, 2018). All athletes signed a voluntary consent to participate in the study.

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Received: 11.04.2022 **Accepted:** 30.05.2022 **Published online:** 23.06.2022

DOI: 10.47183/mes.2022.022

МЕДИЦИНСКАЯ РЕАБИЛИТАЦИЯ В СПОРТЕ ВЫСШИХ ДОСТИЖЕНИЙ ПОСЛЕ РЕКОНСТРУКЦИИ ПЕРЕДНЕЙ КРЕСТООБРАЗНОЙ СВЯЗКИ КОЛЕННОГО СУСТАВА

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Профессиональная деятельность спортсменов спорта высших достижений в условиях нагрузок, близких к экстремальным, часто приводит к травмам нижней конечности. Повреждение передней крестообразной связки (ПКС) — один из наиболее распространенных видов травм коленного сустава. Целью исследования было оценить эффективность комплексной программы реабилитации спортсменов после артроскопической реконструкции ПКС. В исследовании участвовали 64 спортсмена (от 17 до 31 года). Участникам основной группы, проходившим комплексную программу медицинской реабилитации, проводили изокинетические тренировки на биомеханическом комплексе TECNOBODY IsoMove по разработанной методике. Результаты медицинской реабилитации спортсменов оценивали путем анализа походки на аппаратном комплексе DIERS Motion 4D через 8 и 15 недель после операции. Через 8 недель после операции не наблюдалось статистически значимых различий в группах по параметрам анализа походки. Через 15 недель после операции по завершении изокинетических тренировок у спортсменов основной группы (ОГ) по параметру Stand time дефицит в опоре на оперированную конечность (ОК) относительно здоровой конечности (ЗК) составил 0,04%, по параметру «одиночная поддержка» — 3,71%, в сравнении со спортсменами группы клинического сравнения (ГС), у которых по параметру Stand time дефицит в опоре на ОК относительно ЗК составил 12,44%, по параметру «одиночная поддержка» — 18,55%. По параметру Swing-time у спортсменов ОГ дефицит в симметрии переноса ЗК относительно ОК составил 3,99%, а у спортсменов ГС — 20,54%, что статистически значимо и доказывает эффективность разработанной методики изокинетических тренировок в комплексной программе медицинской реабилитации, что привело к более быстрому восстановлению мышечной силы, нарушений опорной и локомоторной функции ходьбы у спортсменов ОГ.

Ключевые слова: ПКС, артроскопия, реабилитация, изокинетические тренировки, анализ походки, высококвалифицированные спортсмены

Вклад авторов: Р. А. Бойченко — обзор литературы, сбор материала, анализ полученных данных, написание текста, определение параметров сравнения походки, статистическая обработка данных; С. В. Горнов — разработка дизайна исследования, редактирование и утверждение финального варианта статьи.

Соблюдение этических стандартов: исследование одобрено этическим комитетом ФГБУ ФНКЦСМ ФМБА России (протокол заседания № 01-09 от 15 сентября 2018 г.). Все спортсмены подписали добровольное информированное согласие на участие в исследовании.

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Статья получена: 11.04.2022 **Статья принята к печати:** 30.05.2022 **Опубликована онлайн:** 23.06.2022

DOI: 10.47183/mes.2022.022

Anterior cruciate ligament (ACL) reconstruction is the main method of treatment of ruptured ACL in elite athletes. Non-contact ACL injuries are most common in athletes aged 15–40 years that practice sports involving sharp changes of the movement biomechanics: football, handball, rugby, volleyball, alpine skiing, etc. [1, 2]. Every year, about 3% of amateur athletes suffer ACL injuries. In the high performance sports realm, this figure can go up to 15% [2]. Women are two to eight times more likely to damage the ACL, a probable reason thereof being the differences in neuromuscular patterns in

men and women during and after puberty [3, 4]. Studies have shown that 35% of elite athletes fail to achieve their previous level of performance within two years after injury [5]. In 2015, Federal clinical guidelines "Rehabilitation of Knee Capsular Ligaments Injuries (Surgical Treatment)" were published [6]. The rehabilitation includes four stages. Duration of the first (early postoperative) and second (late postoperative) stages is up to three to four months, that of the third stage (pre-training) is up to six months, fourth stage (training) — up to a year. Some authors have identified the following timeframes in the four main stages of rehabilitation of patients with ACL injury: early postoperative (1 week); late postoperative (2–4 weeks); functional (5–8 weeks); training and recovery (9–24 weeks) [7]. The program of post-ACL reconstruction rehabilitation [8] allows strength training in the training and recovery period (9–32 weeks) from the ninth week; such training involves use of cable (pulley) machines to load knee and hip joint during flexion and extension exercises. High-class athletes need more advanced exercises to restore muscle strength of quadriceps and hamstring muscles, and these exercises should not put the ACL autograft in danger. Currently, biomechanical exercising machines capable of providing biofeedback meet these requirements better than any other option.

Athletes need accelerated rehabilitation programs, since a long path back to loads common to competitions can translate into deterioration or loss of their professional skills. There are some general post-ACL reconstruction care trends adopted by the orthopedic community, but there is neither a standardized protocol nor an established timeframe for returning to the competition level training loads [9]. Therefore, the rehabilitation of athletes after ACL reconstruction is an urgent topic today.

This study aimed to design a comprehensive rehabilitation program for athletes after arthroscopic ACL reconstruction, develop the isokinetic exercising technique that relies on the TECNOBODY IsoMove biomechanical exercising machine and evaluate the effectiveness thereof.

METHODS

By design, this study was a prospective controlled non-randomized study; it involved 64 athletes aged 17–31 years, all practicing sports that imply extreme locomotor activity; all had their ACL reconstructed. Gender-wise, we recruited 38 (59.4%) women (mean age 22 ± 4.2 years) and 26 (40.6%) men (mean age 26 ± 4.8 years). In all cases, the surgery took place less than a week after the athletes were diagnosed with ACL rupture. The ligament reconstruction materials were autografts of tendons of the semitendinosus and tender muscles, tendons of the long peroneal muscle.

The inclusion criteria were: age 16–40 years; first ever arthroscopic ACL reconstruction with/without partial resection of the meniscus, with/without arthroscopic meniscus suture.

The exclusion criteria were: age below 16 and over 40 years; arthroscopic interventions on adjacent and contralateral joints of the lower limbs; history of knee osteoarthritis; refusal to participate at any stage of rehabilitation.

The total duration of the study was 38 months (from October 2018 to November 2021).

We compared effectiveness of the designed comprehensive rehabilitation program and the one suggested by the Federal clinical guidelines "Rehabilitation of Knee Capsular Ligaments Injuries (Surgical Treatment)" (hereinafter referred to as the Recommendations) in the context of rehabilitation of athletes. The comparison necessitated division of the participants into two groups: treatment group (TG) of 30 individuals that were rehabilitated following the purpose-designed program, and control group (CG) of 34 athletes whose rehabilitation followed the Recommendations.

The rehabilitation of all participating athletes was organized at the Federal Research and Clinical Center for Sports Medicine and Rehabilitation of the Federal Medical Biological Agency. The programs started 3–4 weeks post surgery, which is the

Table 1. Federal Clinical Guidelines (Recommendations) Program

Period	Timeframe	Treatment plan
I, early post-surgery	up to 3–4 months	General developmental exercises for the contralateral limb. Dynamic exercises for non-immobilized joints of the ipsilateral limb. Knee brace allowing leg bending at an angle of 160–150°, which is gradually brought to 100–90°. Isometric muscle tension. Full extension within 2–3 weeks. Passive movements of the patella. Electromyostimulation. Training to use a functional splint and walk with crutches
II, late post-surgery		Removal of immobilizing bracing. Self-assisted dynamic exercises. Relaxation exercises, active-passive exercises. Isometric muscle contractions in limited amounts. Postural exercises (postural treatment techniques). Mechanotherapy with cable (pulley) machines. Hydrokinesitherapy. Massage
III, pre-training	up to 6 months	Therapeutic gymnastics (walking training, running, complexly coordinated exercises with additional weights and resistance). Hydrokinesitherapy (swimming). Mechanotherapy (pendulum type and isokinetic devices for muscle training), exercise machines (bicycle ergometer, stapler, etc.). Massage. Dynamic electrical stimulation. Training sessions adjusted to factor in the phase of postoperative restructuring of connective tissue structures and the functional state of the periarticular muscles
IV, training	up to 1 year	Training of special locomotor capabilities, with the set compiled by a sports coach to factor in specifics of the practiced sport Recovery of special locomotor skills

Table 2. Comprehensive program of medical rehabilitation of athletes after surgery on the knee joint

Phase	Timeframe	Treatment plan	Criteria for transition to the next phase and completion of rehabilitation
I	up to 2 weeks	Extension exercises with a towel roll under the heel, hanging the lower leg out while lying on the stomach on a couch. Motor retraining of the quadriceps femoris muscle (electromyostimulation). Knee brace locked in the full extension position (1st week), then a 30° bend (2nd week). Crutches-assisted limited loading of the limb (1st week — 25%, 2nd week — 50% of body weight) [11]. Arbitrary tension of the anterior and posterior thigh muscle groups, gluteal muscles. Mobilization of the patella. Active flexion/passive extension of the knee joint while sitting on a couch; the range is 0–60°, repetitions assisted with the healthy leg. Straight leg raises (in all planes). For leg raises from supine position the knee brace should be locked at 0°. Exercising on a bicycle ergometer with a short pedal crank. Resistance exercises for thigh muscles. Cardio training and training for the upper shoulder girdle (as tolerated). Local cryotherapy	Ability to raise the operated leg when it is straightened. Absence of flexion-related contracture manifestations. Knee joint motion range from 0 to 60° (assisted). Absence of pain the operated limb when loaded
II	Weeks 3–6	Knee brace bending limits: up to 60° (3rd week), up to 90° (4th week), up to 120° (5th week), up to 140° and more (from the 6th week) [11]. Increased reliance on the operated limb for support (monitor severity of the pain), in the absence of antalgic elements in the gait - refusal of crutches. Exercising on a standard bicycle ergometer (when the knee starts to bend for over 115°). Active and assisted exercises aimed at extending the range of motion. Mini squats/shifting body weight from side to side. Proprioceptive training on unstable platforms, on simulators like a gymnastic spin, with elastic bands on the opposite limb. Beginning of step-up training (step platform height — 10, 15, 20 cm). Training on the stair climber. Straight leg raises with progressive resistance Hamstring and posterior chain muscles training with progressive resistance. Improvement of elasticity of the musculoskeletal system of back of thigh and lower leg. Hardware arthrometry of the knee joint 6 weeks after surgery; no manual examination with application of maximum traction force to the lower leg should be done. Lymphatic drainage massage, electrical stimulation, magnetotherapy, US therapy	Knee joint motion range from 0 to 140°. Normal gait type. Ability to step up to a platform 20 cm high. Restoration of mobility of the patella. Improvement of functional indicators, as registered with arthrometry and motor tests
III	Weeks 7–14	Squats. Beginning of step-down training. Leg presses. Lunges. Knee joint extensions in isotonic mode, range 90 to 40° (preference should be given to exercises in a closed kinematic chain). Advanced proprioceptive training (active unbalancing). Training on the TECNOBODY IsoMove biomechanical exercising machine. Agility development exercises (with stretch cords). Reverse ladder training. Backward walking/running. Thigh and calf muscles stretching. Arthrometry 3 months after surgery. Adjustment of the home training program based on the results of dynamic observation	Unlimited knee joint movement. Ability to descend stairs with a step height of 20 cm without pain, with good control of the leg. Improvement of functional indicators, as registered with arthrometry and motor tests
IV	Weeks 15–21	Running, if the patient descends from a 20 cm step platform successfully. More advanced/difficult strength and flexibility exercises. Advanced sport-specific agility exercises. Plyometric training, if the adequate muscle strength level has been achieved. Knee joint extensions in isotonic mode, full movement range, no pain neither crepitus (preference should be given to exercises in a closed kinematic chain). Home rehabilitation program based on the results of dynamic monitoring of the patient	Symmetric painless running. Minimum symmetry between limbs in the jump test — 75%. Progress in functional training. Successful passing of the functional
V	from week 22	Strength training for the lower limbs with sport-specific elements. Advanced program of plyometric exercises. Use of the knee brace when practicing sports. Dynamic monitoring of the patient's condition and assessment of his/her complaints (pain, swelling). Adjustment of the rehabilitation program, if necessary. Persuading the patient to work out at home on a regular basis. Arthrometry 6 months after surgery	Muscle strength deficit less than 15%, as registered with isokinetic testing. Symmetry over 85%, as registered with a single leg jump test. No pain nor instability during all sport-specific movements. Flexibility as required for the particular sport

II phase in the timeframe of the purpose-designed program. All participants attended the sessions 3 times a week.

The Recommendations program [6] is divided into four periods (Table 1).

The comprehensive rehabilitation program designed in the context of this study has five phases (Table 2).

The comprehensive program of medical rehabilitation included isokinetic training on a machine providing biofeedback. Isokinetic training of muscles in the concentric mode delivered a significant improvement of the quadriceps and hamstring muscle strength (average and maximum torque at angular velocities of 30 and 60° per second) [10]. Biodex 3 System (Model 333–250; Biodex Medical Systems, Shirley; USA) was employed with the following parameters: angular velocity of 180° per second, three sets of 20 repetitions twice a week.

We have proposed a technique involving the TECNOBODY IsoMove biomechanical complex (Figure 1). Isokinetic exercises had the knee flexors and extensors loaded in the concentric mode, with the range of motion from 20 to 110° and angular velocity of 30° per second. The sessions took place twice a week; for the first two weeks, the number of repetitions was 10, then the routine changed to three sets of repetitions for the first two weeks, then twice a week, three sets of 15 repetitions for the next 2 weeks, then three sets of 20 reps for two weeks and then a week with three sets of 20 repetitions. The total number of sessions was 15. The movements started with extension of the knee joint. First, the healthy limb was trained, then the operated one. These training sessions began eight weeks post surgery.

Eight weeks post surgery, during the III phase of the rehabilitation, both groups had the following parameters/indicators assessed: impairments in the support and locomotor functions; lower limbs load distribution symmetry (enabled by DIERS Motion 4D, Figure 2) in the gait analysis mode (pedogait) at the speed of 3 km/h. The repeated control examinations took place 15 weeks post surgery at the end of the isokinetic training program.

The stride cycle (SC) for each limb consists of two main phases, support phase and transfer phase. The duration of the support phase is 58–61% of the SC, that of the transfer phase is 42–39%. The distinction is made between right and left SC, with the two constituting the act of walking [12, 13]. We evaluated CS phases of OL and HL and compared the respective results registered in the TG and the CG. The evaluated parameters were Stand time (%), which is the time the limb supports from the moment the toe is off the ground to the moment heel of the contralateral limb accepts the load; Swing-time (%), which is the time of transfer of the non-supporting limb; Single limb support (%); Load sensitivity (%); Pre-swing (%), which is the time from resting on the toe to bouncing off (Fig. 3). The first three parameters were statistically significant for the comparison.

Statistical processing of the results was done manually in Microsoft Excel and Statistica for Windows v. 5.1. To establish significance of the differences we used Student's t-test. The differences (t) were considered statistically significant at $p < 0.05$.

RESULTS

The following criteria were chosen for an objective assessment of effectiveness of the programs compared: pain assessment on a visual analogue scale (VAS), range of motion, zigzag jump test, stride parameters in gait analysis.

The participants took the jump test 15 weeks after surgery. In the TG, less than 75% symmetry between limbs during the jump was seen in two athletes (6.7%), while in the CG it was registered in nine athletes (26.5%).

In the TG group, four athletes (13.3%) reported pain of 4 VAS points and one (3.3%) — 5 VAS points; in the CG, seven participants (20.6%) put the pain sensation at 4 VAS points and two (5.9%) at 3 VAS points. Three months later, only one athlete (3.3%) reported pain of 2 VAS points in the TG, and in the CG the respective number of participants was 3 (8.8%).

A month later, the recorded active flexion radius in both groups was 100–110°, and passive flexion ranged up to 115–130°. One athlete from the TG had active extension limited to 7° and passive extension to 3°. After months later, no contractures were registered in any of the groups.

Stability tests (Lachman drawer test, pivot shift test) performed 15 weeks later revealed no positive symptoms in any of the TG athletes. In the CG, these tests allowed registering a slight anterior translation of the lower leg with a clear final point.

Fig. 1. TECNOBODY IsoMove biomechanical exercising machine

Fig. 2. DIERS Motion 4D complex

Table 3 shows the results of assessment of violations of the support and locomotor functions, lower limbs load distribution as registered with the DIERS Motion 4D complex.

Eight weeks after surgery, there were no significant differences found between groups in the parameters of support and locomotor functions violations as registered and analyzed with the DIERS Motion 4D complex. However, fifteen weeks after the reconstruction, when the TG members were through all the isokinetic training sessions, the results were as follows: for the Stand Time parameter, the OL support deficit was 0.04% compared to the HL support, and for the Single limb support parameter it was 3.71%, while in the CG the values were 12.44% and 18.55%, respectively. As for the Swing Time parameter, TG participants showed the deficit of HL transfer symmetry (relative to OL) of 3.99%, while the value of this parameter in the CG was 20.54%.

DISCUSSION

The results of the gait parameter analysis for the TG participants indicate a more effective recovery of muscle strength of the knee joint stabilizers, healing of disorders of the support and locomotor functions in the postoperative period that included isokinetic training, which implies resistance when a certain angular velocity is reached, translating into load for exercised muscles. These findings are consistent with those reported by other authors earlier [9, 10]. Therefore, the resistance that the athlete has to overcome is adaptable, it changes constantly

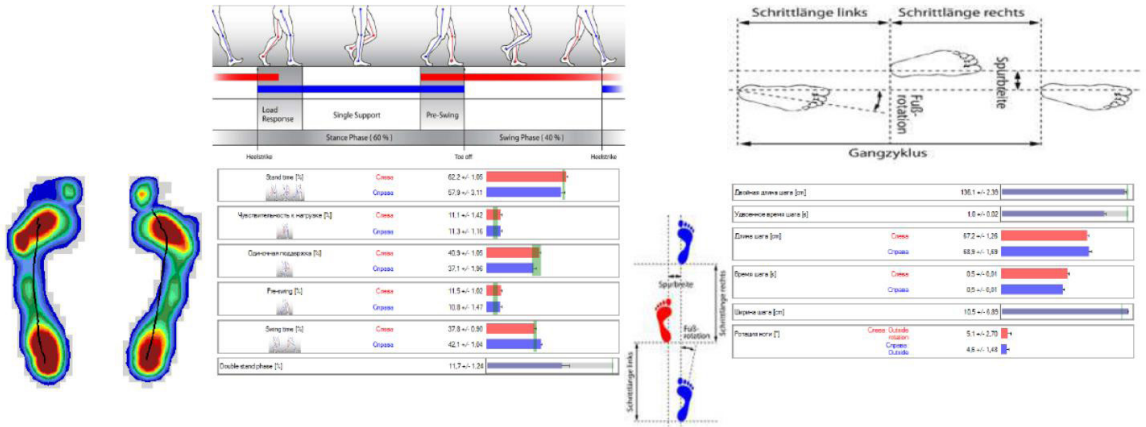

Fig. 3. Gait parameters on the DIERS Motion 4D complex

Table 3. Comparison of the results of examinations of participating athletes

Gait parameters	TG (n = 30) Me/Q_1/Q_3		CG (n = 34) Me/Q_1/Q_3	
	HL	OL	HL	OL
Stand time, %	After 8 weeks			
	68,6/68,03/ 69,75	57,6/55,23/ 59,78	69,15/ 67,05/ 50,45	55,70/ 50,45/ 56,9
Single limb support, %	42,9/37,65/45,23	31,9/31,4/32,6	44,1/ 43,48/ 48,43	31,35/ 30,13/ 32,73
Swing-time, %	31,4/30,3/32	42,4\40,2/44,8	30,85/29,43/ 34,73	44,3/43,1/49,55
Sensitivity to load, %	12,35/11,23/15,4	13,4/11,33/15,58	11,85/10,9/12,3	12,25/11,9/14,18
Pre-swing, %	15,1/12,5/16,7	11,95/11,6/14	12,05/11,6/13,65	11,65/ 11,33/ 13,08
Stand time, %	After 15 weeks			
	65,8/64,4/69,2	63,7/63/65,5	67,5/65,3/68,7	59,1/58,7/60,3
Single limb support, %	36,4/31,1/37,1	35,05/31,2/35,8	41,5/40,2/42,7	33,8/31,6/34,7
Swing-time, %	34,85/31,55/35,58	36,3/33,65/36,98	32,5/31,3/34,68	40,9/39,73/41,28
Sensitivity to load, %	15,2/14,3/18,5	14,7/18,1/18,1	13,4/12,7/14,8	13,5/12,7/14,1
Pre-swing, %	15/14/18,7	15,25/14,2/18,4	13,3/12,7/14,6	13,4/12,9/14,5

Note: Me — (median); Q_1 is the 25% quartile; Q_3 is the 75% quartile; differences between TG and CG at $p < 0.05$.

in proportion to the effort exerted. As a result, the process of muscle strength recovery gain in effectiveness.

CONCLUSIONS

1. The designed comprehensive post-ACL reconstruction medical rehabilitation program for elite athletes has proven to be effective in restoring the knee joint stabilizer strength, healing of the support and locomotor function disorders, poor symmetry in the distribution of load on lower limbs. 2. The use of equipment providing biofeedback for rehabilitation of athletes allows speeding this process up and thus have the athletes recover their competition level capabilities sooner. 3. It is necessary to continue the search for the most effective isokinetic training technique relying on the TECNOBODY IsoMove biomechanical complex.

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