https://doi.org/10.5272/jimab.2025314.6555
Journal of IMAB
ISSN: 1312-773X
https://www.journal-imab-bg.org
Journal of IMAB. 2025 Oct-Dec;31(4)

Original article

MUSCLE STRENGTH RECOVERY AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT:

Anterior cruciate ligament (ACL) rupture is a leading cause of injury among athletes. Achieving full recovery of muscle strength remains a challenge, particularly for professional athletes. Re–rupture of the ligament is often associated with insufficient muscle strength restoration.

Purpose: The purpose of this study is to present a kinesitherapy methodology designed to support muscle strength recovery following anterior cruciate ligament reconstruction.

Material/ Methods: The study included 10 participants who underwent anterior cruciate ligament reconstruction. After regaining joint range of motion, participants engaged in a daily exercise program conducted in a gym setting. The progression of muscle recovery was assessed through monthly anthropometric measurements. Hip circumference was measured using a tape measure, and subcutaneous fat was assessed with a skinfold caliper. The data from the affected leg was compared with that of the healthy limb at three standardized levels.

Results: The analysis revealed a consistent decrease in the differences between the affected and healthy limbs in both hip circumference and skinfold thickness at all three measured levels. A noticeable increase in subcutaneous fat was observed only at the second measurement level (20-22 cm), based on caliper data. These findings indicate a trend toward symmetry in muscle volume recovery during the kinesitherapy protocol.

Conclusions: Muscle strength recovery following ACL reconstruction is a prolonged and complex process. The proposed kinesitherapeutic approach contributed to progressive normalization of anthropometric parameters in the affected limb. Sharing this methodology may help clinicians plan effective rehabilitation strategies and reduce the risk of re–injury.

Keywords: muscle strength, anterior cruciate ligament, hip circumference, caliper,

INTRODUCTION

The anterior cruciate ligament is a key structure in the knee, protecting against anterior instability. It is located between the anterior intercondylar region of the tibia and the lateral femoral condyle. This ligament is made up of two bundles: the posterolateral (stabilizes rotational movements), and the anteromedial (stabilizes translational movements in the anteroposterior direction) [1]. Functionally, it prevents anterior translation of the tibia relative to the femur and ensures rotational stability, particularly during rapid deceleration and directional changes such as pivoting or cutting movements [2].

ACL injuries are common, especially among young, physically active individuals. Epidemiological data indicate an incidence of 68 to 81 cases per 100,000 persons annually in the general population, increasing to 100-200 per 100,000 among athletes involved in sports such as football, basketball, handball, and skiing [3]. Approximately 70 - 80 % of ACL injuries are non–contact in nature, commonly associated with inadequate neuromuscular control during jump landing, sudden deceleration, valgus collapse, or excessive knee hyperextension [4,5]. Contact injuries represent the remaining 20 - 30% and are usually caused by direct blows or collisions [5].

Reconstruction of a torn ACL if followed by a long and critical period of physical rehabilitation. Scientific literature provides a wide range of kinesitherapeutic protocols for muscle strength recovery. However, a common error in practice is premature loading and strength training before the complete restoration of range of motion, which may impair the healing process or predispose the patient to reinjury [6].

In our clinical approach, we emphasize the importance of gradual loading, respecting and plyometric activities until at least the fourth postoperative month. Furthermore, we propose monitoring muscle recovery through thigh circumference and subcutaneous fat thickness, which are non-invasive and objective measures to track progress.

PURPOSE:

The purpose of this study is to present and evaluate a kinesitherapeutic protocol for muscle strength recovery following ACL reconstruction, based on structured progression, objective anthropometric parameters, and adherence to evidence–based loading phases.

MATERIALS AND METHODS:

The study protocol was approved by the Ethics Committee of South-West University "Neofit Rilski" (Blagoevgrad, Bulgaria). All participants and/or their legal guardians provided written informed consent before inclusion in the study.

Participants

Ten male individuals who had completed the initial recovery phase and regained a full range of motion of the affected lower limb were included. All had undergone ACL reconstruction using autografts harvested from the semitendinosus or semimembranosus tendons. Inclusion criteria require unilateral knee joint injury and a minimum age of 13 years.

Functional and anthropometric measurements

Muscle circumference was measured using standard centimeter tape at three predefined levels of the thigh: 8 – 10 cm (Level 1), 20 – 22 cm (Level 2), and 28 – 30 cm (Level 3) above the patella. Subcutaneous adipose tissue thickness was assessed using a skinfold caliper at the same anatomical levels on both the affected and healthy limb. Measurements were performed at baseline and monthly over a 3-month period.

Kinesitherapeutic program

The kinesitherapeutic program was initiated after achieving full restoration of the range of motion in the affected limb, typically between the first and first – and - half months following ACL reconstruction. The full duration of the program was three months, with progression tailored to the patient's recovery stage and physical capacity.

Depending on the applied interventions and goals, the rehabilitation process was structured into three distinct stages:

• ***Stage I-*** corresponding to the first month after the start of the kinesitherapeutic intervention (approximately 1-1.5 months post–ACL reconstruction);

• ***Stage II*** – second month;

• ***Stage III*** – third month of active training.

The program was based on a combination of resistance exercises, ergometric training, and functional outdoor activities. Progression was achieved by adjusting the training frequency, intensity, and load distribution between the injured and uninjured limb. The kinesitherapeutic approach emphasized gradual symmetry restoration in muscle strength and functional abilities.

Stage I – First Month of the Kinesitherapeutic Program

During the first month, the kinesitherapeutic intervention was performed five times per week, primarily in a gym setting. The program combined aerobic warm–up, resistance exercises targeting the lower limbs, and proprioceptive activation.

Each session included the following components:

• Warm–up on cycle ergometer – 10 minutes at moderate intensity;

• Resistance training:

➢ Knee extension and flexion: performed bilaterally with 5 kg resistance, with load distribution of 80% on the unaffected leg and 20% on the operated leg, in order to gradually introduce the involved limb to load–bearing activities;

➢ Hip abduction and adduction exercises with bent knees, using 20 kg resistance;

• Weight–bearing progression: from knee support to seated position, performed in 3 sets of 15 repetitions;

• Cool–down: 20 minutes of low-intensity cycling.

At this stage, the goal was not yet to equalize strength between the limbs, but rather to initiate controlled muscle activation of the operated limb and progressively increase its involvement in strength exercises in a safe, monitored manner.

Stage II – Second Month of the Kinesitherapeutic program

During the second month, the kinesitherapeutic intervention remained structured and progressive, conducted five days per week in a gym-based environment.

The primary objectives of this stage were to increase resistance, expand volume, and progressively involve the operated limb in more symmetrical work compared to the unaffected limb.

The applied protocol consisted of the following elements:

• Warm-up: 10 minutes of cycling on a stationary ergometer at moderate intensity;

• Resistance and strength training;

➢ Knee extension and flexion in the sagittal plane, performed bilaterally with a 5 kg load, where the unaffected limb performs 50% and the operated limb 50 % of the total effort;

➢ Hip abduction and adduction (with flexed knees), performed with 30 kg resistance;

• Quadriceps activation through transition from kneeling to seated position on heels and back to upright kneeling (functional movement performed from a kneeling position), aiming to stimulate strength and control in the m. quadriceps femoris of the operated leg.

• Cool–down: 20 minutes of low-intensity ergometer cycling.

All exercises were executed in seven sets of fifteen repetitions, focusing on correct form, muscle control, and gradual load progression. This stage supports the functional recovery of muscular symmetry, preparing the patient for more demanding dynamic movements in the upcoming phase.

Stage III – Third Month of the Kinesitherapeutic Program

During the third month, the kinesitherapeutic recovery program is performed three times per week in a gym and two times per week outdoor.

Gym session:

The same exercises from the previous months are applied, but the loading is adjusted according to the individual capacity of the affected limb, using a progressive scheme such as 1:3, 2:5, or 3:7 – i.e., one set with the healthy limb and three with the affected limb (or a corresponding ratio). This allows for a gradual increase in the involvement of the affected limb in training.

Outdoor sessions:

• Running on flat terrain – 10 minutes

• Stretching

• Stair running: One flight of stairs (approximately 20 steps); Intermediate landing; Another flight of 20 steps (Three series – rest – another three series)

• Single–leg hops up the stairs, performed following a 1:3 ratio – one set with the healthy leg, three with the affected leg, in order to enhance strength and neuromuscular control on the injured side.

Statistical analysis

All analyses were performed in GraphPad Prism 3.0. Data are reported as mean ± standard deviation (SD). The difference between baseline vs. month 3 was tested using the non-parametric Wilcoxon signed-rank test. A p-value of <0.05 was considered statistically significant.

RESULTS:

The study included 10 male participants with a mean age of 23.10 ± 8.54 years (range: 13 to 39). Among them, six were professional athletes and four were non-professionals. The right leg was affected in six participants, and the left leg in four.

A progressive reduction in the difference between the affected and healthy limbs was observed across all three measured levels of thigh circumference (8 -10cm, 20-22 cm, and 28-30 cm). The greatest improvement was noted at Level 1, where the average asymmetry decreased from 3.75 cm at baseline to 1.65 cm by the third month (Table 1).

Table 1. Difference in thigh circumference (affected vs healthy limb) over three months

Level	Baseline	Month 1	Month 2	Month 3	*p – value (BL vs M3)
Level 1 (8-10cm)	3.75	2.92	2.41	1.65	0.0059
Level 2 (20-22 cm)	3.03	2.61	2.1	1.79	0.0039
Level 3 (28-30cm)	2.57	2.52	1.67	1.19	0.0127

**BL- baseline (initial measurement); M3- measurement at the end of month 3. p-values were calculated using the Wilcoxon signed–rank test*

The skinfold caliper measurements demonstrated a similar trend. The most notable reduction in subcutaneous tissue thickness occurred at Level 3 (28-30 cm), decreasing from 5.29 mm at baseline to 0.79 mm after three months (Table 2). At Level 2 (20-22 cm), a transient increase was observed in the first month, followed by a marked decrease thereafter.

Table 2. Difference in skinfold thickness (affected vs healthy limb) measured by caliper.

Level	Baseline	Month 1	Month 2	Month 3	p – value (BL vs M3)
Level 1	6.18	5.17	2.95	2.16	0.0098
Level 2	5.76	5.18	2.89	1.3	0.0109
Level 3	5.29	3.37	2.77	0.79	0.0039

**BL- baseline (initial measurement); M3- measurement at the end of month 3. p-values were calculated using the Wilcoxon signed–rank test*

These results highlight a consistent and measurable improvement in muscular symmetry and subcutaneous tissue distribution during the rehabilitation period.

DISCUSSION:

Despite the broad scientific consensus, some rehabilitation protocols or clinical practices tend to initiate resistance exercises before achieving complete joint mobility, especially in flexion, which may lead to persistent pain, joint irritation, and compensatory movement patterns. According to Adams et al. (2012), premature strength training without adequate mobility may delay neuromuscular re-education and increase the risk of re–injury [7]. Therefore, our approach emphasizes strict compliance with the sequence: first achieving optimal joint amplitude, then gradually introducing strength exercises adapted to the stage of tissue healing and joint loading tolerance.

In the literature, numerous kinesitherapy methodologies have been proposed, including isokinetic, neuromuscular, and proprioceptive approaches [8,9]. However, not all of them offer objective criteria for tracking soft tissue restoration, especially the regaining of lean muscle mass. The methodology applied in our study is based on a progressive load principle and combines circular training of the lower limb (with alternating concentric and eccentric movements in flexion-extension, abduction – adduction), proportional activation of the injured limb in relation to the contralateral one, and gradual transition from closed kinetic chain exercises to dynamic functional movements [10,4].

A specific contribution of our approach is the systematic tracking of thigh circumference and subcutaneous fat in defined anatomical regions, which provides an objective measure of muscle mass restoration. The observed increase in thigh circumference and reduction in skinfold thickness in the injured limb support the hypothesis that the applied kinesitherapeutic strategy contributes not only to functional recovery but also to qualitative tissue adaptation. This is consistent with the findings of Palmieri–Smith and Thomas (2009), who emphasize that muscle atrophy after ACL reconstruction is often underestimated and should be closely monitored through anthropometric parameters [11].

Moreover, our results are in line with the conclusions of Gramatikova (2024), who emphasizes the importance of using functional and anthropometric tests to monitor rehabilitation in patients with complex knee injuries, such as O'Donoghue's Triad [12]. Although our study focuses on isolated ACL reconstruction, the principle of analytically chosen diagnostic tools and individual progression in comparable.

The restriction of impact activities, such as running until the fourth postoperative month, was strictly observed in our methodology. This decision was supported by recent consensus statements recommending delayed return to high-impact activities to ensure sufficient graft integration and neuromuscular readiness [13, 14].

In summary, the methodology we propose offers a structured and evidence–informed approach to progressive rehabilitation following ACL reconstruction. By integrating objective anthropometric tracking, respecting physiological healing phases, and applying progressive muscular activation, it aligns with current expert recommendations and provides additional tools for assessing muscle recovery. The observed results in our study group demonstrate that such an approach ensures not only effective but also measurable functional restoration.

CONCLUSIONS:

The restoration of muscle strength following ACL reconstruction is a prolonged and demanding process that requires strict adherence to the phases of the kinesitherapeutic program. Return to sports activity should occur only after full restoration of muscle function and symmetry between muscle and adipose tissue.

The proposed kinesitherapeutic method has demonstrated effectiveness through clearly traceable anthropometric indicators – thigh circumference and subcutaneous fat thickness. These simple, non–invasive measurements provide reliable objectification of muscular recovery and can serve as valuable components of the standard functional assessment protocol in post–ACL reconstruction rehabilitation. Dissemination of this methodology and promotion of the evaluation parameters may contribute to more effective recovery and better planning of return to active physical activity.

Abbreviations:

ACL - anterior cruciate ligament
ROM – range of motion
SD – standard deviation

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Please cite this article as: Zlatkova K, Zlatkov Y. Muscle strength recovery after anterior cruciate ligament reconstruction. *J of IMAB.* 2025 Oct-Dec;31(3):6555-6559. [Crossref - https://doi.org/10.5272/jimab.2025314.6555]

Received: 30/07/2025; Published online: 23/10/2025

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