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Results Muscle Strength and Thickness After Anterior Cruciate Ligament Reconstruction with Hamstring Tendon Autografts: An Ultrasonographic and Isokinetic Evaluation

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Abstract

BACKGROUND/AIMS: This study aimed to compare the muscle strength and thickness of individuals who underwent anterior cruciate ligament (ACL) reconstruction using a hamstring tendon graft for at least 12 months with uninvolved limbs and healthy controls.

MATERIALS and METHODS: This study included 25 individuals who underwent ACL reconstruction [age: 29.56±8.25 years; Body Mass Index (BMI): 27.27±3.89 kg/cm^2] and 25 healthy participants (age: 27.12±5.94 years; BMI: 24.70±3.03 kg/cm2). Muscle thicknesses of the vastus medialis oblique (VMO), rectus femoris (RF), biceps femoris (BF), and semitendinosus-semimembranosus (SS) muscles were evaluated by ultrasonographic measurement. Muscle strength measurements using an isokinetic system were performed.

RESULTS: VMO ($p<0.001$) and RF ($p<0.001$) muscle thickness were higher in the uninvolved limb than in the surgical limb. The concentric quadriceps muscle ($p=0.029$), eccentric quadriceps muscle ($p=0.012$), and eccentric hamstring muscle strengths ($p=0.001$) were significantly higher in uninvolved limb, which was similar concentric hamstring muscle strength ($p>0.05$). Muscle thickness and muscle strength of the control group and the surgical limbs were similar ($p>0.05$).

CONCLUSION: An average of 3 years has passed since the operation; however, VMO and RF muscle atrophy and decreased hamstring and quadriceps muscle strength continued. These results revealed that the use of the limb, which has not fully achieved its functionality, is limited, and individuals try to compensate for this situation by the uninvolved limb.

Keywords: Anterior cruciate ligament; muscle thickness; muscle strength; ultrasonographic measurement; isokinetic evaluation

INTRODUCTION

Injuries of the anterior cruciate ligament (ACL), which play an important role in joint stability,[1] are the most common knee injuries due to sports-related lower extremity injuries. These injuries can jeopardize athletic careers by reducing physical activity in athletes.[2] Following ACL injury, varying degrees of atrophy and strength are observed in the lower extremity

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muscles.[3] Therefore, the most important part of rehabilitation after ACL surgery is the restoration of the quadriceps and hamstring muscle strengths.[4] The quadriceps muscle has an important role in knee joint stabilization and the quadriceps muscle strength is associated with functional performance and development of osteoarthritis in the long term, thus the rehabilitation after ACL surgery should primarily focus on the treatment of this muscle.[5] Several treatment approaches have been developed to strengthen the quadriceps muscle after the ACL reconstruction; however, the literature has reported that muscle strength cannot be restored to pre-injury level.[6]

The hamstring muscle plays a synergistic role with the ACL.[7] The strength and neuromuscular function of the hamstring muscle group is important in ACL injury prevention. Therefore, the ACL must be preserved.[8] Hamstring activity relatively decreases quadriceps activation and leads to injury risk in the ACL.[8] Following surgery, the decreased strength in the hamstring muscles is due to neural inhibition that occurs in this area due to grafting of the hamstring muscle and changing mechanics in musculotendinous structures.[9] Therefore, in the postoperative period, the thigh muscles should especially be evaluated in detail for atrophy.[10]

The literature has reported that atrophy of the quadriceps muscle may be present both in the early term and at the return-to-sport phase, which is considered to be postoperative 6 months after ACL reconstruction surgery.[11] Studies have investigated the effects of hamstring and quadriceps muscles after ACL reconstruction; however, the results of hamstring muscles, in particular, are controversial.[12-14] Additionally, many studies compared the surgical limb with the uninvolved limbs. However, deficits in muscle strength are also seen in the knee after surgery, and this condition is attributed to cross-over inhibition or insufficient fitness.[15,16] This shows that comparing the muscle strength on the surgical limb with the uninvolved limb does not yield accurate results.[16] Therefore, studies must conduct comparisons with a healthy control group to achieve more accurate results. Based on this information, this study aimed to examine the quadriceps and hamstring muscle thickness and strength of participants who underwent ACL reconstruction surgery at least 12 months ago via ultrasonography and isokinetic system and compare the results with that of healthy participants.

MATERIALS and METHODS

Participants

This study evaluated 77 patients who underwent ACL reconstruction surgery using hamstring tendon grafts between 2013 and 2016 for eligibility criteria. Inclusion criteria are ACL surgery, ages 18–45 years, unilateral ACL reconstruction surgery with a hamstring tendon autograft at least 12 months before the study initiation, and no injuries for at least 12 months in both lower limbs. Patients with accompanying posterior cruciate ligament, lateral collateral ligament, or medial collateral ligament and meniscus injury in the same knee, biopsy, tibial plate fracture, joint movement range restriction, quadriceps or patellar tendon graft, cartilage injury, previous surgery on the lower limbs, and accompanying systemic or neurological problems were excluded from the study. This study included 25 patients.

The control group evaluated 28 healthy individuals aged 18–45 years who did not have any knee injury or surgery in the last 12 months, were not diagnosed with a disease, and who voluntarily agreed to participate in the study. Individuals in the control group were selected from those with similar age, gender, and physical activity level to those who underwent ACL reconstruction. An International Physical Activity Questionnaire short form was used to determine the level of physical activity.[17,18] The study included 25 healthy participants. The flowchart of the individuals is shown in Figure 1.

Before initiating the study, all participants were informed about the study, and written consent with their agreement to participate in the study was obtained. Ethics committee permission was obtained from the ethics committee of the university with the decision dated 06.13.2016 and numbered 326.

Procedure

The age, height, body weight, and dominant limb were recorded for all participants. Additionally, the limbs with ACL injuries, the dates of ACL injury and surgery, pre-existing musculoskeletal injuries, post-surgical treatment, and duration of treatment were also evaluated.

Before the assessments for the study, individuals were given a 5-min warm-up of 5 minutes of walking on the treadmill at self-selected speeds.

Tests were performed starting from the uninvolved limb in individuals who underwent ACL surgery and from the dominant limb in the control group.[19,20] The dominant limb was determined by evaluating the limb the individuals used in kicking a ball or jumping.

Ultrasonographic muscle thickness measurements were performed with B-mode ultrasonography using the 7.5–12 MHz linear probe (LOGIQ 7 Pro; GE Yokogawa Medical System, Tokyo, Japan). The Vastus medialis oblique (VMO) and rectus femoris (RF) muscle thicknesses were measured in the supine position. For the VMO muscle thickness measurement, the probe was placed 4 cm proximal and 3 cm medial to the superomedial border of the patella, parallel to the muscle fibers, in the oblique-sagittal plane.[21] For the RF muscle thickness measurements, the distance between the superior border of the patella and Spina iliaca anterior superior were measured and marked, and the probe was placed at the midpoint.[22,23]

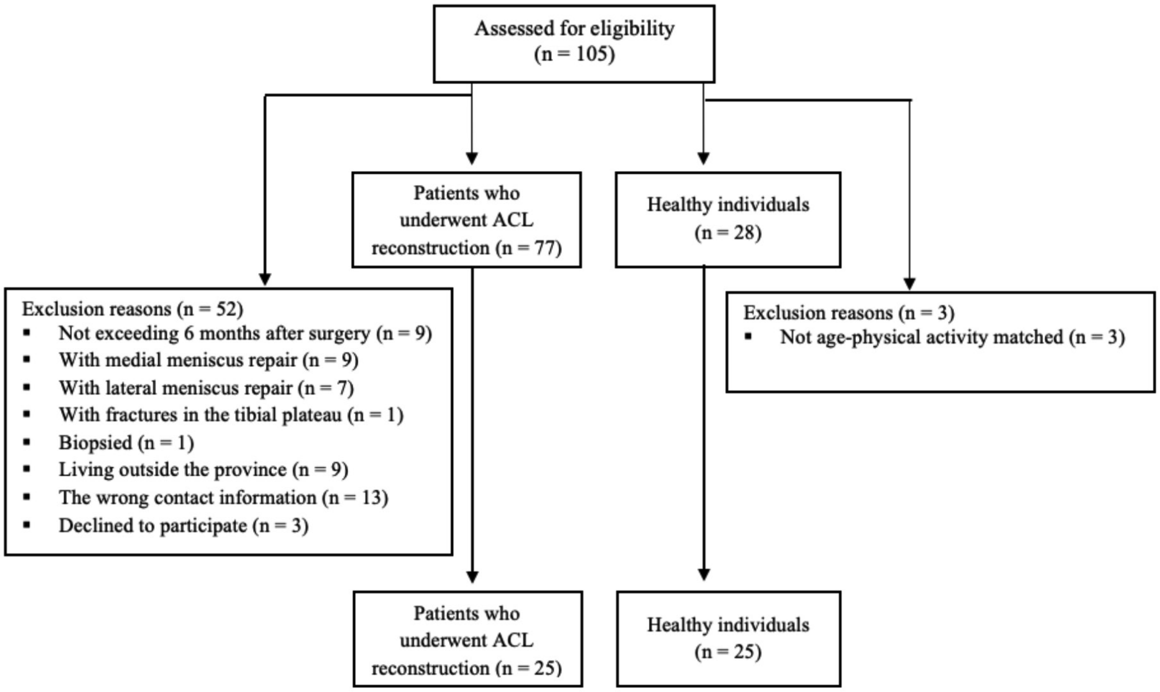

Figure 1. The follow diagram of patients who underwent ACL reconstruction and healthy individuals in the study

Muscle thickness measurements of the biceps femoris (BF) and semitendinosus-semimembranosus (SS) muscles were performed in the prone position. For the BF muscle thickness measurement, the midpoint of the distance between the lateral condyle of the femur and the ischial tuberosity were determined and the midpoint of the distance between the medial condyle of the femur and the ischial tuberosity were used to measure the SS muscle thickness.[22] The water-soluble permeable gel was used to provide acoustic contact between the probe and the skin. The obtained ultrasonographic images determined the muscle-subcutaneous fat interface and muscle-bone interface. The distance between the interfaces was used to measure the muscle thicknesses of VMO, RF, BF and SS.

Muscle strength measurements were performed in a sitting position using the isokinetic system (Cybex NORM®, Humac, CA, USA). Individuals were fixed with a strap from the shoulders, waist, and thighs to prevent compensatory movements during the test. For the ankle, the strap was placed 3 cm proximal to the malleolus.[19,20] Simultaneously, both verbal and visual feedback was given during the tests for individuals to achieve maximum effort.[19] Concentric strength evaluation of the quadriceps femoris and hamstring muscles was performed in the knee flexion ranging 0–90 degrees at 60°/s velocity. The tests were initiated from 90 degrees of knee flexion. Before the test, three submaximal warm-up repetitions were performed. After 1 minute of rest, five maximal test repetitions were performed.[24] The eccentric muscle test was performed with five repetitions at a speed of 60°/s in the knee flexion range 20–90 degrees. After two attempts, a 1-minute rest period was given. The test of the quadriceps femoris muscle was initiated at 20 degrees of knee flexion, whereas the hamstring muscle was initiated at 90 degrees knee flexion position.[25] During all tests in the isokinetic system, peak torque/body weight values were obtained for hamstring and quadriceps muscles from both limbs.

Statistical Analysis

Statistical analyses were conducted using the statistical package for social sciences version 22.0 (SPSS INC, Chicago, IL, USA) software. The normal distribution of variables was examined using visual (histogram and probability graphs) and analytical methods (Kolmogorov-Smirnov test). For descriptive statistics, mean ± standard deviation or median and range of values, and interquartile range were calculated. The difference between the limbs of individuals who underwent ACL surgery and the control group was analyzed using the "Independent groups t-test" in cases of normal distribution and the "Mann-Whitney U test" in the absence of normal distribution. For the comparison between the limbs in the group that underwent ACL surgery, the "Paired t-test" was used for normally distributed variables. Without normal distribution, the "Wilcoxon test" was used. *P*-values below 0.05 were evaluated as statistically significant results.

RESULTS

The demographic characteristics of participants were presented in Table 1. A mean of 34.08±14.97 months had passed since

Table 1. Demographic characteristics of participants

		ACL groups (n=25, mean ± SD)	Control groups (n=25, mean ± SD)	*p*-value
Age (years)		29.56±8.25	27.12±5.94	0.502
Body weight (kg)		84.22±13.35	78.09±12.67	0.402
Height (cm)		175.64±8.04	177.48±7.31	0.102
BMI (kg/m²)		27.27±3.89	24.70±3.03	0.012*
Physical activity level (MET/min)		2,034.80±1,858.46	2036.48±1599.23	0.946
Sex, n (%)	Female	4 (16%)	5 (20%)	
	Male	21 (84%)	20 (80%)	
Dominant limb, n (%)	Right	18 (72%)	25 (100%)	
	Left	7 (28%)	0 (0%)	
Surgery limb, n (%)	Right	12 (48%)		
	Left	13 (52%)		

*Statistically significant association ($p < 0.05$).
ACL, Anterior cruciate ligament; BMI, Body mass index; MET, Metabolic equivalent task; SD, Standard deviation; n, Number

the individuals underwent ACL surgery (12–60 months). Rehabilitation after surgery was received by 16 (64%) patients, whereas 9 (36%) did not. The mean duration of rehabilitation following the surgery was 8.12±3.89 weeks (2–16 weeks).

In the control group, data were compared obtained from the dominant and non-dominant limbs to determine the limb to be used for comparison, which revealed no difference between the two limbs ($p > 0.05$). Therefore, the comparisons were performed by matching the limbs that underwent surgery with the same side limb of the control group.

The comparison of VMO, RF, BF and SS muscle thickness of the surgical limb and the uninvolved limb of the individuals revealed that the muscle thickness of VMO ($p < 0.001$, Table 2) and RF ($p < 0.001$, Table 2) to be significantly greater in the uninvolved limb. However, the values of the BF and SS muscle thicknesses of the surgical and uninvolved limbs were similar ($p > 0.05$). The comparison of the surgical limb and the matching limb of the control group revealed that the muscle thicknesses are similar both groups ($p > 0.05$, Table 2).

The comparison of the two limbs of the group that underwent surgery revealed a significantly higher concentric quadriceps muscle ($p = 0.029$, Table 2), eccentric quadriceps muscle ($p = 0.012$, Table 2), and eccentric hamstring muscle strength ($p = 0.001$, Table 2) in the uninvolved limb, which was similar to the concentric hamstring muscle strength ($p > 0.05$, Table 2). The comparison of the surgical limb and the control group revealed similar muscle strength measurement results ($p > 0.05$, Table 2).

DISCUSSION

The study results that examined individuals who underwent ACL reconstruction surgery at least 12 months ago revealed that atrophy of VMO and RF muscles and weakness in the hamstrings and quadriceps muscles continued even though an average of 3 years had passed since the surgery.

Volume changes occur in the affected muscles after the ACL reconstructive surgery.[26] The literature reported that in the postoperative period, after an ACL injury, decreases are observed in the activity and corresponding mechanical stimulation, which reduces the load on the surgical extremity. Arthrogenic muscle inhibition is associated with pain, inflammation, swelling, and damage to joint proprioceptors and leads to the atrophy of the quadriceps muscles.[27] Ten patients who underwent ACL reconstruction surgery using hamstring tendon grafts were evaluated 9–10 years after surgery with magnetic resonance imaging (MRI). Their MRIs revealed semitendinosus muscle atrophy and BF muscle hypertrophy.[28] These results suggest that the morphological changes due to ACL surgery occur not only in the grafted muscles but also in other peripheral muscles.[26] The quadriceps muscle mass was evaluated using MRI in the preoperative and postoperative periods in a study with 25 patients who had undergone ACL reconstruction surgery and revealed that the muscle mass decreased in the surgical limb at the preoperative assessment and the assessments performed in the fourth and twelfth postoperative weeks. Therefore, quadriceps atrophy was largely related to the quadriceps muscle weakness.[27] Another study conducted with 22 individuals who underwent surgery evaluated the quadriceps muscle mass using MRI and concluded that a lower cross-sectional area of the quadriceps muscle in the surgical limb. Therefore, muscle atrophy has been associated with the loss of muscle strength. Additionally, treatment approaches were emphasized to prevent muscle strength loss and atrophy after surgery.[29] The study performed by Williams et al.[13] examined the preoperative and

Table 2. The comparison of muscle thickness and muscle strength

		Surgical limb (mean ± SD)	Uninvolved limb (mean ± SD)	*p*-value Surgical vs. uninvolved limb	Control groups limb (mean ± SD)	*p*-value Surgical vs. controls limb
Cross-sectional area (cm)	VMO	2.44±0.54	2.72±0.53	0.000*	2.46±0.47	0.894
	RF	4.58±0.67	4.94±0.68	0.000*	4.64±0.75	0.535
	BF	4.69±0.52	4.87±0.63	0.121	4.54±0.58	0.312
	SS	5.64±0.60	5.81±0.56	0.092	5.76±0.73	0.510
Concentric strength PT/BW (N/kg)	Quadriceps	147.44±45.17	159.56±44.08	0.029*	173.96±58.48	0.079
	Hamstring	79.16±24.66	82.56±28.02	0.413	89.28±33.33	0.228
Eccentric strength PT/BW (N/kg)	Quadriceps	195.04±61.57	220.28±57.82	0.012*	205.44±67.62	0.572
	Hamstring	104.88±27.62	118.16±28.07	0.001*	110.92±30.77	0.469

*Statistically significant association ($p < 0.05$).
VMO, Vastus medialis obliqus; RF, Rectus femoris; BF, Biceps femoris; SS, Semitendinosus-semimembranosus, PT/BW, Peak torque/body weight; SD, Standard deviation

postoperative (after the subject had returned to sports) MRI results of eight individuals who underwent ACL reconstruction surgery using hamstring tendon grafts and revealed a decreased volume of the semitendinosus muscle in the surgical limb, and BF and semimembranosus muscle hypertrophy was evident compared with the uninvolved limb. Results that were interpreted as atrophy might be ongoing as tendon regeneration processes and are incomplete.

The MRI results before surgery and at the third and twelfth postoperative months concluded that semitendinosus muscle atrophy continued after surgery in all nine patients who underwent ACL reconstruction surgery using a hamstring tendon graft compared with the uninvolved limbs. This study revealed that the loss of hamstring muscle strength continued in addition to the atrophy. Additionally, most study participants neither received enough physiotherapy nor participated in at-home exercise programs. The presence of atrophy has been interpreted with these concerns.[14] The gracilis and semitendinosus tendons that are preferred as autografts in ACL reconstruction procedures explain the semitendinosus muscle atrophy. However, a different study stated that the MRI results of 22 individuals who underwent ACL reconstruction surgery at least 5 months ago (range: 4–91 months), and 22 healthy controls showed no difference in the volume in their knee flexor muscles (SS and BF). Additionally, despite the neurologic dysfunction in the quadriceps muscle, no neurologic dysfunction was found in the hamstring muscles.[12]

Our study revealed similar BF and SS muscles thicknesses of the surgical limb and the uninvolved limb. The thicknesses of VMO and RF muscles on the uninvolved limb were higher than the surgical limb. This finding might be because the uninvolved limb is used more during the activities of daily living, and exercises and thereby are more activated. Given the similarity of the results with the uninvolved limb, because of the fear of re-injury, the use of the surgical limb may have been avoided leading to the overuse of the uninvolved limb, thus, causing an increased muscle strength of the uninvolved limb. Additionally, the individuals who received physiotherapy after ACL reconstruction were generally given bilateral strengthening training, causing an increased uninvolved limb muscle strength, thus the uninvolved limbs may be higher than their surgical limbs. The comparison of the surgical limb with the healthy controls revealed similar muscle thicknesses of all muscles.

After ACL surgery, muscle function decreases, and abnormal functional movement patterns occur that may persist for a long time.[30] Following knee surgery, permanent weakness may affect the quadriceps muscle, which is the basis for normal knee functions.[31] Thus, one of the first goals after ACL surgery is quadriceps muscle strength restoration.[32] The weakness of the hamstring muscles may lead to problems during the rehabilitation process and re-injury because they have a crucial role in protecting the ACL and must compensate for the loss of stability in the knee in the presence of an ACL injury.[33] The medial (SS) and lateral (BF) hamstring muscles contribute differently to knee stability.[8] The SS muscles are responsible for the internal rotation and varus stresses in the knee, whereas the BF is responsible for external rotation and valgus stresses.[8] The weakness of the hamstring muscles and the low co-activity regarding the quadriceps muscle also increase the risk of an ACL injury.[33] Therefore, strength measurements following ACL surgery and rehabilitation are important objective results.[34]

A study that evaluated individuals who underwent ACL reconstruction surgery using hamstring tendon grafts after six years revealed no strength deficits in the hamstring and quadriceps muscles according to the muscle strength measurement results using the isokinetic system.[35] Another study in individuals who underwent ACL surgery and were evaluated after 51 months considered rehabilitation strategies as ineffective in quadriceps function improvement. However, their study participants were operated on by different surgeons and with different rehabilitation programs, therefore whether quadriceps weakness was caused by the rehabilitation programs or arthrogenic muscle inhibition was unclear.[20] Our study revealed that both the eccentric and concentric muscle strength of the quadriceps muscle and the eccentric muscle strength of the hamstring muscle was lower than those of the uninvolved limb in the comparison between the surgical and uninvolved limbs. Many studies have emphasized the relationship between the presence of muscle strength and atrophy. Our study results reflected the atrophies in the VMO and RF muscles in the strength results. The comparison of the surgical limb with the matching limb of the control group revealed similar muscle strength results.

CONCLUSION

Our study investigated the rates of rehabilitation and revealed that nine patients (36%) did not receive rehabilitation after surgery. The period of rehabilitation examination revealed the mean duration of rehabilitation as 8.12±3.89 weeks (range: 2–16 weeks). The ideal rehabilitation program should last approximately 6 months after an ACL repair, thus this period is insufficient. In our opinion, the treatment duration was very short for some patients, and these treatment periods were not long enough to eliminate the deficits that occurred after surgery. These differences related to the rehabilitation process may have led to different results. The atrophy and muscle strength losses may continue despite an average of 3 years after surgery because of insufficient rehabilitation periods.

The limitations of our study include the different rehabilitation programs in our study participants in the postoperative period. Additionally, ACL injuries are problems that are mostly seen in females; however, our low number of female cases might be another limitation. Moreover, we do not have preoperative measurement data of individuals who underwent ACL reconstruction.

This study revealed that after having ACL reconstructive surgery, participants returned to their daily lives or sports activities with muscular strength imbalances and morphological differences in VMO and RF muscles. Therefore, the use of the limb, which has not fully achieved its functionality, is limited and individuals try to compensate for this situation by over-using the uninvolved limb. An adequate and well-planned physiotherapy program after ACL surgery is required for lower limb functionality. Determining the current problems by evaluating the individuals in detail in the long term after surgery is important and rehabilitation programs should be developed to provide solutions to these problems.

Main Points

• Individuals who underwent ACL reconstruction had muscle strength imbalances and morphological changes in the VMO and RF muscles even with an average of three years since the surgery.

• The use of the limb, which has not fully achieved its functionality, is limited and individuals try to compensate for this situation by over-using the uninvolved limb.

• Determining the current problems by evaluating the individuals in detail in the long term after surgery is important and rehabilitation programs should be developed to provide solutions to these problems.

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ETHICS

Ethics Committee Approval: Ethics committee permission was obtained from the Ethics Committee of Gazi University with the decision dated 06.13.2016 and numbered 326.

Informed Consent: Before initiating the study, all participants were informed about the study, and written consent with their agreement to participate in the study was obtained

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Authorship Contributions

Conception: S.S.K.; Design: S.S.K., Supervision: N.G., N.K., M.B.A.; Data Collection and/or Processing: S.S.K., G.Ç., Z.G.; Analysis and/or Interpretation: S.S.K., N.G., G.Ç., N.K.; Writing: S.S.K.

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