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Knee Objective Stability and Isokinetic Thigh Muscle Strength after Anterior Cruciate Ligament Reconstruction: A Randomized Six-Month Follow-Up Study

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Abstract

Purpose: The most frequently used grafts for intra-articular anterior cruciate ligament (ACL) reconstruction are the autologous patellar tendon (PT) or doubled semitendinosus and gracilis tendons (STG) autografts. There are still controversies about graft selection for primary ACL reconstruction.

Methods: A prospective, randomized study was conducted on 57 patients who underwent arthroscopically assisted ACL reconstruction between January 2010 and February 2011. In 29 patients ACL reconstruction was performed with hamstring tendon autograft (STG group), and in 28 patients the ACL reconstruction was performed with patellar tendon autograft (PT group). At 6 months follow-up, all patients have performed the isokinetic extensor and flexor muscles strength and KT-1000 measurements.

Results: At 6 months after surgery, we found significantly lower average isokinetic quadriceps peak torque in the PT group compared to the STG group at angular velocity of 60°/s. However, at the same time we did not find significant difference in flexor muscle power comparing both groups. The manual maximum KT-1000 arthrometer side-to-side difference was 1.7 ± 1.7 mm for the PT group and 1.9 ± 1.6 mm for the STG group (P=0.398). No significant correlation was found between the knee objective stability (KT-1000 measurements) and the isokinetic thigh muscle strength (extensors, Spearman's rho=0.057, P=0.671; flexors, Spearman's rho=0.094, P=0.489).

Conclusions: Both hamstring and patellar tendon autografts provided good objective stability at 6 months after surgery In addition, regardless of which graft was used, a considerable percentage of patients continue to have strength deficits. In our opinion, the ACL-reconstructed leg should have 85% or greater return to the strength of the normal leg as one criterion before release to full sports activities. We were particularly intrigued to find only half of the competitive athletes achieved this goal at 6 months after surgery.

Keywords: Anterior cruciate ligament (ACL) reconstruction; Hamstring tendons (STG); Patellar tendon (PT); Isokinetic muscle strength; Knee laxity; Randomized clinical study

Introduction

The anterior cruciate ligament (ACL) rupture is the most common serious injury of the knee. It is widely believed that knee injury with associated ACL tear may lead to functional instability. In the active sporting population, such instability has been found to be associated with muscle weakness, meniscal and chondral injuries as well as with the development of degenerative disease within the joint [1-3]. The goals of ACL reconstruction are to decrease symptoms, improve function, and return patients to their pre-injury level of activity in the short term. ACL reconstruction is a common procedure that usually allows predictable and timely return to function for the patient [2]. It is customary now to allow return to full activities 6 months after the procedure, with some surgeons advocating return to sports as early as 4 months [4].

Because of numerous biologic advantages, the most frequently used grafts for intra-articular ACL reconstruction are the autologous patellar tendon (PT) or doubled semitendinosus and gracilis tendon (STG). Patellar tendon autograft has been the gold standard in ACL reconstruction, but during the last fifteen years, the use of hamstring tendons autograft has increased [5]. Disadvantages of patellar tendon autograft are potential increase in patellofemoral pain, loss of sensation, patellar fracture, inferior patellar contracture, and risk of persistent quadriceps muscle weakness [1,6,7]. Disadvantages of hamstring tendons autograft include potential loss of sensation, hamstring muscle weakness, and slower healing of the graft attachment site [5,8,9]. Weak hamstring muscles and low co-activity in relation to quadriceps are associated with a risk of ACL re-injury, and hamstring weakness is associated with poorer knee function after ACL reconstruction. Many questions have been raised as a result of accelerated rehabilitation programs. One area of concern is that of muscle weakness of the involved extremity due to donor-site morbidity. Several investigators have shown significant thigh muscle weakness that is present beyond the 6 months postoperative time period when using the two common ACL substitutes [1,4] Second area of concern is objective stability of the reconstructed knee. Postoperative accelerated rehabilitation must prevent thigh muscle atrophy in the early postoperative period, but not compromise stability of the reconstructed knee.

Despite an abundance of literature on ACL reconstruction and its outcome, there is little data directly comparing isokinetic thigh muscle strength after ACL reconstruction using patellar tendon and hamstring tendons autograft. The purpose of this prospective randomized study was to evaluate and analyze objective stability and isokinetic strength of

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knee extensor and flexor muscles at 6 months after ACL reconstruction using two different autografts (PT versus STG) with identical fixation (interference screws) in patients undergoing the same accelerated rehabilitation program. The hypotheses of this study were: 1) there is significantly lower quadriceps muscle power in the PT group compared with the STG group 2) there is no significant difference in flexor muscle power comparing both groups 3) there is no significant differences in knee laxity measurements between the two study groups 4) there is no correlation between objective stability and thigh muscle strength.

Materials and Methods

Patient selection

In this randomized controlled study, the key indication for arthroscopically assisted ACL reconstruction was a clinical diagnosis of ACL rupture in a patient desiring to return to his or her pre-injury level of activity. Patients with multi-ligament injury, previous surgery, an abnormality seen radiographically, chondral lesions diagnosed by arthroscopy, or an abnormal contralateral knee, as well as those who did not wish to participate in a research program, were not included into the study. Also, patients who required at ACL reconstruction additional meniscus repair were excluded from the study. From September 2009, the patients who fulfilled the study inclusion criteria were automatically included into the hospital database for ACL reconstruction. From January 2010 to February 2011, fifty-seven patients were randomized to primary arthroscopically assisted ACL reconstruction with a hamstring tendon autograft (N=29) or a patellar tendon-bone autograft (N=28). All patients signed an informed consent form.

The comparison between the hamstring tendon (STG) and the patellar tendon (PT) groups in relation to preoperative and intraoperative parameters showed that both groups were comparable. None of the patients´ radiographs shoved evidence of knee joint osteoarthritis. There were no significant differences between the two groups regarding age, sex, preinjury activity level, preoperative Lysholm knee scores, interval from injury to surgery, and meniscal resection (Table 1). Meniscal resections were performed in 20 of 29 STG patients (68%) and in 19 of 28 PT patients (65%) (P=0.408).

All procedures were performed by the first author (M.S.). The operations were performed using general or spinal anesthesia and a bloodless field. Antibiotic prophylaxis was given before tourniquet inflation as a single dose of 2 g cephalothin. Both groups were operated on using a single-incision technique. A systematic arthroscopic examination was performed initially and then additional surgery was performed. The ACL remnants were cleared away and a lateral notchplasty were performed when necessary.

Variable	Hamstring tendon group	Patellar tendon group	*P*
Total no. of patients	29	28	
Mean age, year (range)	27 (17 -51)	25 (18 - 52)	
Gender (n)			
Male	24 (83%)	24 (85%)	
Female	5 (17%)	4 (15%)	
International Knee Documentation Committee (IKDC) Preinjury activity Level 1	17 (58%)	18 (64%)	
Mean preoperative Lysholm scores (range)	57 (9 - 81)	55 (14 - 77)	0.622
Subacute reconstruction	4 (13%)	4 (14%)	
Chronic reconstruction	25 (87%)	24 (86%)	
Meniscal resection	20 (68%)	19 (65%)	0.408
Partial resection (Less than 30%)	12 (60%)	11 (57%)	
Subtotal resection (More than 30%)	8 (40%)	8 (43%)	0.039

Table 1: Comparison of Randomized Groups.

Operative technique

Apart from the graft harvesting the surgical technique was identical. For the patients randomized to the patellar tendon group, a 10-mm graft was harvested via longitudinal incision as a free autograft. The defects of the patella and the proximal tibia were not bone grafted. The graft included a 25-mm trapezoidal patellar bone block and a 15-mm rectangular tibial bone block. The bone blocks were trimmed to pass through a 9-mm diameter gauge. For the patients in the STG group, the graft was harvested through a longitudinal incision at the site of the pes anserinus insertion. The sartorius fascia was split and the gracilis and semitendinosus tendons were harvest with a tendon striper. The tendons were cleaned and looped over the No. 2 Vicryl absorbable suture to create a quadruple graft and the graft was sized between 7 and 9 mm. The graft was pretensioned up to 20 pounds with the surgeon's hands.

The femoral tunnel was drilled through the anteromedial portal prior to tibial tunnel drilling. The femoral tunnel was drilled through the most medial anatomic footprint of the posterolateral bundle, while the tibial tunnel was drilled through the central part of the anatomic footprint. Drill guides were used to confirm the correct position of the tunnels. To drill the femoral entry point, the author used the "bull's eye" drill guide (Linvatec, Largo, FL.). Tunnel size in the patellar tendon group was made 1 mm larger than the bone block size. In the hamstring tendons group, tunnel size was matched to the cross-sectional size of the graft. A marking suture using No. 0 absorbable suture was set 2.5 cm from the femoral end of the graft to ensure good entry of the graft in the tunnel and to prevent the graft from twisting around the screw during insertion. The graft was inserted via the tibial tunnel into a blind femoral tunnel. The left thread or right threads round-head, cannulated interference screws (RCI, ART-MAM, Slovenia) was used for femoral graft fixation [9]. In right knees the screw with left thread was used and in left knees the screw with right thread was used. In right knee the left thread screw turns in left direction and pushes the transplant away from lateral wall of the intercondylar notch, and vice versa. This fact prevented graft impingement against the lateral wall of the intercondylar notch. Tibial anatomical joint line fixation was achieved by absorbable interference screw (Linvatec) in an outside-in direction at a knee flexion angle of approximately 10° and manual pretension of the graft.

Postoperative rehabilitation

After skin closure and wound dressing, a cold compression device (Aircast, Inc., Summit, New Jersey) was applied and used during the first postoperative week. All the patients went through the same aggressive rehabilitation program, which permitted immediate full weight-bearing and full range of motion without use of rehabilitation brace (Annexure 1). During the hospital stay (mean, 3 days), the focus was set on ROM, muscles control, and pain/swelling management. After 2 weeks, closed kinetic chain exercises and stationary bicycling were started. The rehabilitation program has been completed in the Spa and Rehabilitation Center. After 8 weeks, agility training and light jogging were permitted. After 10 weeks, increased agility workouts, maximum strength training, and sport-specific activities were started. The patients were permitted to go back to full sports participation after 6 months if the criteria of full range of motion, no effusion, and good knee stability and strength were met.

Evaluation

Follow-up measurements were performed at 3 and 6 months

postoperatively in the Spa and Rehabilitation Center by the same senior physical therapist, which was not directly involved in the patient's rehabilitation and not blinded to the type of surgery (Table 2). The isokinetic evaluation has been performed first and then followed with knee laxity measurements.

Isokinetic strength of the extensor and flexor muscle groups was measured with the isokinetic dynamometer En – Knee (Enraf – Nonius). The subjects were told not to participate in any strenuous activities the day before the test session. They were also asked to continue their activities of daily living as usual before test session. The testing protocol was standardized to ensure reproducibility and validity. They performed a 10-minute warm-up on stationary bicycle. The patients were instructed on use of the isokinetic machine and allowed to become fully accustomed to the device before testing. The subjects also performed practice trials before the measurements were taken (pre-test). If a subject reported pain in the leg during the test, which occurred in few cases, this particular test was cancelled and the measurement was repeated. The uninvolved leg was evaluated first, followed by the involved limb. The strength tests (Endurance and Power test) were chosen to reflect quadriceps and hamstring muscle power during knee extension and knee flexion, respectively (open kinetic chain exercises). The peak torque values of the isokinetic strength tests were measured and then expressed as the difference between the involved and uninvolved limb and as the hamstring to quadriceps (H:Q, hamstring divided by quadriceps) ratio.

Objective anterior AP knee laxity measurements were performed by using the KT-1000 arthrometer (MEDmetric, San Diego, CA) [10]. The laxity data were recorded as the side-to-side difference in anterior tibial translation.

Statistical analysis

On September 23, 2009, a hospital database with all pre and postoperative variables was established. Statistical analysis was performed by an independent expert, not involved in the study protocol. Median (range) values are presented, except for the absolute anterior KT-1000 arthrometer laxity measurements, for which mean (range) values are presented. Unpaired *t*-test was used for the normally distributed numerical data (KT-1000 arthrometer). A non-parametric analogue was used, where appropriate (Mann-Whitney test was used to compare the differences between the groups. Spearman's rank correlation coefficient was used to assess the association between objective stability and isokinetic thigh muscle strength. A *P* value less than 0.05 was considered statistically significant.

Results

All 57 patients in the study were available at 3 and 6 months follow-up evaluation. There were no infections, deep venous thrombosis, nerve injuries, or other operative complications in this series. The median length of hospital stay was three nights (range, 2 to 3) for the hamstring tendon group and four nights (range, 2 to 5) for the patellar tendon group. All patients were comfortable with postoperative rehabilitation protocol. Full extension was achieved during early postoperative period. There were no signs of arthrofibrosis or impingement syndrome, so further surgeries were not required.

Comparison of the isokinetic results among the two graft sources showed general similarities (Table 3). The average deficit of the Endurance test (3 months after ACL reconstruction) for extensor muscles in the STG group was 18.8%. The average peak torque of the Endurance test for flexor muscles of the involved leg in the STG group was almost 95% of the uninvolved leg. The average deficit of the Endurance test of extensor muscles in the PT group 3 months after ACL reconstruction was 21.5%, and deficit of flexor muscles was minimal (3.9%). Between the two groups we did not find any statistical significant difference.

Endurance test	Power test	Anterior tibial translation
3 months postoperatively	6 months postoperatively	6 months postoperatively
angular velocity of 180°/s	angular velocity of 60°/s	KT- 1000 arthrometer
ROM 20°- 90°	ROM 10°- 90°	manual maximum force
25 repetitions	6 repetitions	average of 3 measurements

Table 2: Isokinetic and knee laxity evaluations.

		Group STG		Group PT		*P* (STG/PT)
		Average deficit (%)	SD	Average deficit (%)	SD	
Endurance test 180^0/s	Extensor muscles	18.8	14.6	21.5	17.6	0.527
	Flexor muscles	5.2	13.2	3.9	8.6	0.667
Power test 60^0/s	Extensor muscles	14.0	9.7	26.7	10.3	0.001
	Flexor muscles	3.9	16.8	1.4	10.1	0.497

Table 3: Group average deficit (%) and standard deviations (SD) for isokinetic strength measures comparing involved and uninvolved leg at 180^0/s and 60^0/s velocity and the level of statistical significance.

Patients have performed isokinetic Power test at 6 months postoperatively. In the STG group, the average deficit of peak extensor torque was 14.0%. The average peak flexor torque of the involved leg in the STG group was 96% of peak flexor torque of the uninvolved leg. In the PT group, the average deficit of peak extensor torque was 26.7%, and the average deficit of peak flexor torque was minimal (1.4%). We have found a statistical significant difference between the two groups in the extensor muscles power, while we did not find any statistical significant difference in flexor muscles power.

The patients with the hamstring tendons autograft had lower H:Q ratio in the injured leg than the patients with the patellar tendon autograft (0.60 vs. 0.79, $P < 0.001$), but not in the uninjured leg (0.54 vs. 0.56, P=0.415).

There was no significant difference between the groups with respect to the objective stability of the reconstructed knee (Table 4). At 6 months´ follow-up, the manual maximum KT-1000 arthrometer side-to-side difference was 1.7 ± 1.7 mm for the patellar tendon group and 1.9 ± 1.6 mm for the hamstring tendon group (P=0.558).

No significant correlation was found between the knee objective stability (KT-1000 measurements) and the isokinetic thigh muscle strength (extensors, Spearman's rho=0.057, P=0.671; flexors, Spearman's rho=0.094, P=0.489). There was no correlation between the KT-1000 side to side difference measurements and the isokinetic extensor muscle strength in either group (STG group, P=0.853; PT group, P=0.341). However, a moderate correlation was found between the knee objective stability and the isokinetic flexor muscle strength in the PT group (Spearman's rho=0.616, $P < 0.001$), but not in STG group (Spearman's rho=0.232, P=0.227).

KT-1000 measurements at 6 months postoperatively Manual maximum difference (mm)				
Group STG		Group PT		Statistical significance (STG/PT)
Average (mm)	SD	Average (mm)	SD	
1.9	1.6	1.7	1.7	P = 0.558

Table 4: KT-1000 measurements with average differences, standard deviation (SD) and statistical significance.

Discussion

In a prospective randomized trial, we compared the use of the well-established and the most frequently used central third bone-patellar tendon-bone autograft (PT) with use of a doubled semitendinosus and gracilis tendon (STG) autograft. Apart from the graft, all other important factors for the clinical outcome, such as surgeon experience, fixation technique and the rehabilitation protocol, were identical. Numerous studies have recently been published comparing patellar and hamstring tendon autografts in arthroscopic ACL reconstruction [1-9,11-14]. The present study continues to provide ongoing data showing the similarities and differences in the clinical results between the two groups. The results of our study substantiate the similarities found in previous reports that document that good or excellent results may be obtained in the majority of ACL reconstructions when using either PT or STG autografts [4,11,13]. However, Ageberg et al. [5], Aune et al. [1], and Bizzini et al. [6] reported significantly better isokinetic results in the PT group.

Strength deficit, secondary to graft harvesting, has been one area cited as to why neither STG nor PT grafts have been the ideal solution for the ACL reconstruction. Many studies reported that the extensor muscle strength was significantly worse in the PT group [1,7,8,15] and the flexor muscle strength was worse in the STG group [1,5-7] With the increasing efforts to expedite the return not only of the athlete to the playing field, but also the worker back to productive employment, ACL rehabilitation programs have progressed substantially in the recent past. Studies in which more aggressive rehabilitation was permitted have demonstrated improved leg strength with both graft types during earlier rehabilitation period. Carter et al. [4] found no statistically significant differences between the groups in knee extension or flexion strength at angular velocity of 180°/s and 300°/s at 6 months postoperatively. Our isokinetic evaluation confirmed their results at angular velocity of 180°/s already at 3 months postoperatively. At 6 months postoperatively, we found significantly lower isokinetic quadriceps peak torque (percentage of the contralateral side) in the PT group compared with the STG group at angular velocity of 60°/s (Table 3). Regarding the fact that the measurements was performed at 6 months after ACL reconstruction the results were good as according to the literature the reduced extensor muscles strength (on average up to 10%) is a normal phenomenon after ACL reconstruction [6,8,16] and that it can improve for several years after the surgery [17].

Lautamies et al. [8] recorded, even 5 years after the ACL reconstruction, that the subjects in both groups (PT and STG) had significant weaker thigh muscle strength in the involved leg compared with the uninvolved one. The reasons for bad results could be in irreversible preoperative tight muscle atrophy, inadequate operative therapy or/and inappropriate postoperative rehabilitation. The thigh muscles strength reduction is also influenced by the time from injury to surgery. Due to the consequently unstable joint the functional ability of knee joint is reduced, which leads to long term weakness in the leg muscles and compensation with the healthy extremity [1]. In our clinic the waiting time for ACL reconstruction is very long and preoperative rehabilitation programs are inhomogeneous, therefore, the ignorance of this factor can be one of the reasons for the significant difference in extensor muscle strength in the PT group at 6 months postoperatively. However, we did not find significant differences in respect to the waiting time for operative procedure comparing both groups (Table 1). There was significantly lower quadriceps muscle power in the PT group but not in the STG group. The reason for the reduced thigh muscles strength can also be the fact that the injury itself and the operation initiate changes in the neurocentral sensory apparatus, which can lead to changes in the neuromuscular activation of thigh muscles in comparison with the uninjured population [18]. One of the problems of ACL reconstruction with use of the patellar tendon autograft is the presence of postoperative anterior knee pain [1] and the increased possibility of patellar dysfunction [12].

Our accelerated rehabilitation protocol is focused on immediate postoperative passive and active extension of the knee and muscles activation of the whole leg. Full weight-bearing without using the brace enables rapid restoration of physiological walk and thus prevents development of leg muscles atrophy. The early stages of rehabilitation takes place under the expert supervision of a surgeon and it includes 14-day rehabilitation in the Rehabilitation Centre, where patients are instructed carefully on the proper way of doing exercises and gradual increase of activities. In the late stage of rehabilitation there is less physiotherapy control, however, patients are motivated to participate in objective testing at 3 and 6 months after the surgery. The advantage of our research is in the fact that all subjects were operated by the same surgeon and the rehabilitation process was led by the same physiotherapist. This is relatively rare in researching and represents a priority over research where more experts are included [16]. Based on the results we can confirm the effectiveness of the whole rehabilitation protocol. Despite the fact that the accelerated rehabilitation protocol was identical for both groups the extensor muscle strength was significantly worse in the PT group.

Considering the flexor muscle strength, measured at 3 months and at 6 months after surgery, the average deficit between the involved and the uninvolved leg was less than 5% in both groups. This is a very good result, particularly in the STG group because previous research has found that the hamstring tendons harvest significantly reduces the flexor strength for approximately 1 to 2 years after surgery [5,1,6]. Aune et al. [1] reported a significant difference in measurements of flexor muscle strength to the benefit of PT group. The results are justified with the presence of pain in the back of the knee and the reduced possibility of compensation of other muscles, especially the m. biceps femoris. Bizzini et al. [6] came to the same results where the cause for the difference was the trauma of flexor muscles during the surgery. The findings of our research do not confirm this. Excellent results resulted from good surgery technique of an experienced surgeon as well as rehabilitation program focusing on due and proper stretching and strengthening of flexor muscles.

The hamstring muscles play a major role in preventing or decreasing anterior and rotatory displacement of the tibia relative to the femur. Because the hamstring muscles are ACL agonists, recovery of hamstring muscle strength is of importance after ACL reconstruction, and it may be argued that this is of particular importance after reconstruction with the hamstring tendons autograft. Ageberg et al. [5] based on the results of their study suggested that a high H:Q ratio may be an important factor for dynamic knee-joint stabilization and seems to be relevant to the patient after ACL reconstruction. We agree with that conclusion, but results of our study proved that a high H:Q ratio in PT group correlated with a low quadriceps muscle power of the patients.

Beyaz et al. [14] reported no significant difference between patients who underwent single and dual-bundle ACL reconstruction in terms of hamstring and quadriceps isokinetic muscle strength at any angular velocities. In this prospective, randomized study semitendinosus and gracilis tendons ware used as autograft for ACL reconstruction. Probably that is the reason why they did not get any statistically significant differences in correspondence to isokinetic thigh muscle strength.

Numerous studies reported that both hamstring and patellar tendon autografts provided good objective stability [1,7,11,13]. In our study, there was no significant difference between the groups with respect to the objective stability of the reconstructed knee. At 6 months follow-up, the KT-1000 arthrometer side-to-side difference was 1.7 ± 1.7 mm for the patellar tendon group and 1.9 ± 1.6 mm for the hamstring tendon group (P=0.558). However, Bizzini et al. [6] reported that the PT group reaching significantly better results.

No significant correlation was found between the knee objective stability (KT-1000 measurements) and the isokinetic thigh muscle strength (extensors, Spearman's rho=0.057, P=0.671; flexors, Spearman's rho=0.094, P=0.489).

The strength of this study is the RCT design, the high follow-up rate and the independent observer assessment. The main limitation of our study is relatively small number of the patients who were included in our research. In order to obtain more reliable results, well-controlled, prospective long-term studies comparing patellar tendon with hamstring tendons autograft are needed.

Our study results showed that an appreciable quantity of patients had not regained adequate strength to be released to full sports activities without concern. In our opinion, the ACL-reconstructed leg should have 85% or greater return to the strength of the normal leg as one criterion before release to full sports activities. We were particularly intrigued to find only half of the competitive athletes achieved this goal at 6 months after surgery.

Conclusion

The strength deficiencies found in our study concur with what has previously been shown in regard to ACL reconstruction. In addition, regardless of which graft is used, a considerable percentage of patients continue to have strength deficits. At 6 months after surgery, we found significantly lower isokinetic quadriceps peak torque in the PT group compared with the STG group at angular velocity of 60°/s. However, at the same time we did not find significant difference in flexor muscle power comparing both groups. We did not find significant differences in knee laxity measurements between the two study groups. No significant correlation was found between the knee objective stability and the isokinetic thigh muscle strength.

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