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Clinical and functional outcomes and proprioception after a modified accelerated rehabilitation program following anterior cruciate ligament reconstruction with patellar tendon autograft

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Objectives: The aim of this study was to evaluate the clinical and functional outcomes and proprioceptive function in patients who received a modified accelerated rehabilitation program after anterior cruciate ligament (ACL) reconstruction with a patellar tendon (PT) graft.

Methods: The study included 38 patients (33 men, 5 women; mean age 27.6±6.4 years; range 18 to 45 years) who underwent ACL reconstruction with a PT graft and participated in a modified accelerated rehabilitation program. Only six patients were athletes. Isokinetic strengths of concentric knee extension and flexion were measured with the Cybex isokinetic dynamometer, and static balance was tested with the Sport-KAT device. For proprioceptive assessment, active repositioning was measured at knee flexions of 40°, 20°, and 5° with an isokinetic dynamometer. Activity levels and subjective functional results were evaluated with the Tegner activity scale and Lysholm knee score, respectively. For objective functional testing, single leg hop, triple leg hop, and one-legged crossover hop tests were used. Knee stability was assessed with the Lachman test and anterior drawer test and knee range of motion was measured. The mean follow-up period was 16.2±9.8 months.

Results: There was no graft failure during the follow-up. Twenty patients (52.6%) had hypoesthesia at the donor site and 15 patients (39.5%) had anterior knee pain. Before surgery, all the patients had positive results in the Lachman and anterior drawer tests. After surgery, the Lachman test was negative in 32 patients (84.2%), while six patients (15.8%) had grade 1 laxity. The mean Lysholm knee score showed a significant increase postoperatively ($p<0.001$). The mean preoperative and postoperative Tegner activity scores were not significantly different ($p>0.05$). There were no significant differences in the range of motion between operated and uninjured extremities ($p>0.05$). The two extremities were similar in proprioception and balance ($p>0.05$). Isokinetic quadriceps muscle strength was significantly decreased in the operated extremity only in extension at 60°/sec angular velocity ($p<0.05$). Other muscle strength measurements were similar in both extremities. The ratios of flexion/extension muscle strength were significantly greater in the involved extremity at all angular velocities ($p<0.05$). The mean performance scores of three functional tests were more than 85% of the uninvolved extremity. All the patients returned to preinjury daily activities or sports activities in 6 to 12 months postoperatively.

Conclusion: We had satisfactory clinical, proprioceptive, and functional results in achieving dynamic and static stability of the knee with the modified accelerated rehabilitation program after ACL reconstruction with a PT graft.

Key words: Anterior cruciate ligament/injuries/surgery/rehabilitation; knee joint/rehabilitation; muscle strength; physical therapy modalities; proprioception; tendons/transplantation.

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The anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee and its injuries result in significant functional impairment. Surgical reconstruction of a ruptured ACL with autogenous graft materials is advocated as the treatment choice, particularly for individuals who intend to resume competitive sports activities.[1]

The two most commonly used autogenous grafts are the central third of the patellar tendon (PT) and hamstring tendon. Both graft materials are associated with excellent results and have similar properties with regard to laxity and strength. Patellar tendon graft is still one of the most popular autogenous grafts for intra-articular reconstruction of the ACL.[2-4]

An integral element in achieving a favorable outcome following ACL reconstruction is participation in the postoperative rehabilitation.[5] Rehabilitation following ACL reconstruction has undergone a relatively rapid and global evolution over the years. The current trend in rehabilitation after ACL reconstruction has been towards an increasingly aggressive restoration of motion and strength, with an accelerated return to sporting activities at 4-6 months after surgery. Rehabilitation is focused on maintaining cardiovascular conditioning, proprioception, and muscular coordination with appropriate exercises.[6]

The aim of this study was to evaluate muscle strength, proprioception, balance, functional capacity, and activity levels of patients who received a modified accelerated rehabilitation program following ACL reconstruction with a PT graft.

Patients and methods

The study included 38 patients (33 men, 5 women; mean age 27.6±6.4 years; range 18 to 45 years) who underwent ACL reconstruction with a PT graft between 2000 and 2007 and participated in the modified accelerated rehabilitation protocol (Table 1). The right limb was dominant in 36 patients. Reconstruction was performed in the dominant limb in 20 patients. The characteristics of the patients are given in Table 2.

Exclusion criteria were as follows: history of injury or surgery in the same knee, concomitant tear of the posterior cruciate ligament, simultaneous collateral ligament repair during surgery; pathologies of the hip, knee, and ankle leading to knee pain; history of cardiopulmonary disease that can interfere with isokinetic testing and functional measurements; history of ophthalmologic and neurologic disease that can limit stabilometric measurements.

The subjects were scheduled to follow-up visits at 3, 6, 8, and 12 weeks, and at 3 and 6 months postoperatively to evaluate outcome and to increase motivation for the rehabilitation. The mean follow-up period was 16.2±9.8 months. Patients whose follow-up results were not found satisfactory were enrolled into an inpatient rehabilitation program. The subjects were allowed to return to sports activities gradually based on the results of isokinetic and functional tests. Only six of the patients were athletes. Time to return to vigorous daily activities or recreational sports varied from six to 12 months postoperatively.

Assessments

For objective functional testing, we used single leg hop test,[6,7] triple leg hop test,[3] and one-legged crossover hop for distance.[3] The tests were performed three times for each leg, and the means of each limb were calculated and used to determine limb symmetry. Limb symmetry was calculated by dividing the mean score of the involved limb to the mean score of the uninvolved side and multiplying the result by 100.[6]

Isokinetic strengths of concentric knee extension (quadriceps) and concentric knee flexion (hamstring) were measured with a Cybex NORM isokinetic dynamometer. Before testing, the subjects performed a standardized warm-up for 15 minutes. The subjects were placed in the dynamometer chair in an upright position with 90° hip flexion. The subjects were allowed to have trial tests to familiarize themselves with the equipment and the test procedure before five cycles of maximal reciprocal concentric isokinetic knee extensions and flexions at angular velocities of 60°/sec, 180°/sec, and 240°/sec. Strength was measured as the peak torque at these velocities.

Proprioception was assessed with joint position sense of the knee by measuring the ability of reproduction of active position (RAP)[8] using the Cybex NORM isokinetic dynamometer. The knee was extended slowly from 90° flexion to flexions of 40°, 20°, and 5° for 10-second periods. The subjects were instructed to remember these angles and asked to reproduce these knee positions after the knee was then returned to 90° flexion. The ability to actively reproduce these knee positions at three different target an-

Table 1
Postoperative rehabilitation protocol following anterior cruciate ligament (ACL) reconstruction

Rehabilitation protocol after ACL reconstruction should follow several basic guiding principles.

1. Achieving full range of motion (ROM) and reduction in inflammation and swelling to avoid arthrofibrosis.
2. Early weight-bearing and ROM exercises with emphasis on obtaining early full extension.
3. Early initiation of quadriceps and hamstring activity.
4. Efforts to control swelling and pain to prevent muscular inhibition and atrophy.
5. Timely and appropriate use of open and closed kinetic chain exercises to avoid shear or tear of the weak immature ACL graft due to early initiation of open chain exercises.
6. Comprehensive exercises to increase lower extremity muscle stretching, strength, and conditioning.
7. Functional training.
8. Cardiovascular training.
9. Stepped progression to achieve therapeutic goals.

0-2 weeks

Goals:

1. Achieve full extension, 90° knee flexion
2. Wound healing
3. Good quadriceps control
4. Minimal swelling

- Apply ice for 10 min at every hour, elevate leg with the knee in full extension
- Ankle ROM exercises, passive knee extension to 0°, passive knee flexion to tolerance
- Isometric quadriceps exercises
- If quadriceps control is enough, straight leg raises in all planes
- CPM to increase ROM of the knee (two times daily, starting from 10 min based on tolerance)
- Straight leg raises (if the patient tolerates 10-15 repeats, 3 sets, weights may be added to the proximal tibia)
- Active hamstring curl
- Prone leg hang
- Add wall sliding when the patient achieves 80-90° knee flexion
- Patellar mobilization
- Brace locked in full extension, partial weight-bearing with crutches
- Active knee ROM from 90° to 40° flexion

2-4 weeks

- Drop-lock brace to allow full ROM
- Continue prone leg hang to preserve full extension, passive knee extension if needed
- Knee flexion must reach 120° at the end of week 4
- Prone and standing hamstring curl with weights
- Closed kinetic chain exercises
- Stationary bicycle
- Proprioceptive strengthening program
- Lateral step up exercise
- Full weight bearing without crutches

4-6 weeks

- Discontinue brace at week 4
- Full ROM must be reached at week 6 (full extension is important)
- Strengthening program with closed kinetic chain exercises (wall-squats)
- Lunges

8-10 weeks

- Lateral strengthening and agility exercises
- Progression in proprioceptive exercises
- Plyometric exercises

12-14 weeks

- Isokinetic testing for hamstring and quadriceps strength, if quadriceps strength reaches 70% of the uninjured leg, proceed with jogging program
- Continue all exercises
- Progress in plyometric exercises
- Isokinetic quadriceps exercise (if needed)

16-18 weeks

- Sport-specific training

5-6 months

- Quadriceps strength can be tested if needed
- Gradual return to sports if quadriceps and hamstring strengths reach 85% of the uninjured leg
- Continue sport-specific training

gles from 90° flexion to 40°, 20°, and 5° flexion was noted. The differences between the perceived angle and the actual angle were recorded. For each limb, all angle measurements were repeated three times and the means were calculated, and then compared with the uninvolved extremity.

Measurements of balance were made on the kinesthetic ability trainer equipment (Sport-KAT 2000), which has been found reliable in balance testing.[9] The static test was performed on one foot, with the arms crossed over the shoulders and the other extremity at 20° flexion. The subjects were asked to hold the

Table 2
Characteristics of the patients

	Mean±SD	Range
Age	27.6±6.4	18-45
Body mass index (kg/m^2)	25.1±2.6	19.8-31.3
Preoperative time (months)	15.4±19.0	1-72
Postoperative time (months)	16.0±9.8	6-40

cursor at the center of the screen for 30 seconds while keeping their balance. The result was scored as the balance index (BI) by the equipment. The test was repeated three times and the mean BI score for each subject was calculated.[9]

Activity of the patients was evaluated using the Tegner activity scale with a maximum score of 10.[10] Subjective symptoms of the patients were evaluated using the Lysholm knee score with a maximum score 100.[11] Preoperative and postoperative Tegner activity scores and Lysholm scores were compared and analyzed.

Knee stability was assessed with the Lachman test and anterior drawer test before and after surgery. In the Lachman test, the severity of anterior translation was defined as follows: 1-5 mm: grade 1 (mild) laxity; 6-10 mm: grade 2 (moderate) laxity; >10 mm grade 3 (severe) laxity.

Knee range of motion was measured with a standard goniometer.

All numerical data were expressed as mean± standard deviation. The paired t-test was used to determine the statistical differences between the involved and uninvolved extremities.

Table 3
Mean functional performance scores of three trials

Limb symmetry*	Mean±SD	Range
Single hop for distance (%)	85.5±17.5	44.7-100
Triple hop for distance (%)	88.2±15.0	32.9-100
Cross over hop for distance (%)	91.2±17.2	39.5-100

*Limb symmetry is the percentage obtained by dividing the mean score of the involved limb by the mean score of the uninvolved limb and the result is multiplied by 100.

Results

There was no graft failure, nor contralateral ACL tear in the patients during the follow-up. Twenty patients (52.6%) had hypoesthesia at the donor site and 15 patients (39.5%) had anterior knee pain.

In subjective functional assessment, the mean Lysholm knee score showed a significant increase from 62.1±16.9 to 62.1±16.9 postoperatively ($p<0.001$). The mean preoperative and postoperative Tegner activity scores were not significantly different (5.2±1.6 and 5.1±1.4, respectively; $p=0.64$). Twenty-four patients (63.2%) could reach preoperative Tegner activity levels.

Before surgery, all the patients had positive results in the Lachman and anterior drawer tests. After surgery, the Lachman test was negative in 32 patients (84.2%), while six patients (15.8%) had grade 1 laxity.

The mean performance scores of three functional tests were more than 85% of the uninvolved extremity (Table 3). The scores of 26 subjects (68.4%) were at least 85% of the uninvolved extremity.

There were no significant differences in proprioception of operated and uninjured extremities

Table 4
Joint position sense of the knee and static balance measurements*

	Involved extremity (Mean±SD)	Uninvolved extremity (Mean±SD)	*p*
Joint position sense (°)			
40°	4.6±3.0	5.0±2.8	0.58
20°	5.6±3.9	4.8±3.2	0.28
5°	4.8±3.6	3.8±2.9	0.13
Static balance index	344.7±110.6	341.2±128.8	0.84

*Joint position sense of the knee was determined by measuring the ability of the patient to reproduce active position at three different target angles from 90° flexion to 40°, 20°, and 5° flexion. The values given as mean±SD represent differences between the perceived angle and the actual angle. Measurements of static balance were made with Sport-KAT 2000.

Table 5
The mean peak torques of both limbs for extension and flexion

	Involved extremity (Mean±SD)	Uninvolved extremity (Mean±SD)	*p*
Flexion			
60º/sec	71.2±25.9	71.2±22.9	0.97
180º/sec	46.8±18.8	44.0±18.8	0.22
240º/sec	35.6±16.7	32.5±17.7	0.07
Extension			
60º/sec	110.4±40.1	128.1±41.1	**0.001**
180º/sec	69.3±23.0	74.2±29.9	0.17
240º/sec	52.3±19.9	55.6±25.4	0.22
Flexion/Extension			
60º/sec (%)	67.7±17.3	56.8±11.4	**0.002**
180º/sec (%)	67.2±14.2	59.5±10.8	**0.007**
240º/ sec (%)	66.6±14.1	55.8±15.4	**0.000**

at all angles (p>0.05). In addition, static balance measurements in the operated extremity did not differ significantly from those of the uninvolved side (p>0.05, Table 4).

There were no significant differences in the range of motion between operated and uninjured extremities. The mean flexion was 138.2±4.5° in the operated knees compared to 139.0±4.2° in the uninvolved extremity (p=0.08), the corresponding values for the mean extension were 10.1±0.8° and 00.0±0.0, respectively (p=0.32).

Isokinetic quadriceps strength was significantly decreased in the operated extremity only in extension at 60º/sec angular velocity (p<0.05, Table 5). The ratios of flexion/extension muscle strength were significantly greater in the involved extremity at all angular velocities (p<0.05). There were no significant differences between the involved and uninvolved extremities in other muscle strength measurements.

Discussion

The postoperative rehabilitation program following ACL reconstruction plays an important role in the clinical outcome and patients' satisfaction. In parallel with our understanding of the biology and biomechanics of the knee and improvements in graft reconstruction techniques, rehabilitation programs after ACL injuries have also evolved. Arthroscopic techniques have allowed the use of accelerated rehabilitation protocols that focus on early motion. An ideal rehabilitation program must be slow enough to avoid damage to healing tissues, but also must be fast enough not to cause limitations in the range of motion and muscle atrophy.[12-14] For this reason, we used a modified accelerated program (Table 1) which largely relies on that proposed by Shelbourne and Nitz.[13] All the patients wore a knee brace or an immobilizer during the first 3 to 4 weeks after surgery.

Recovery of knee joint function and successful return of the patients to preinjury activities are crucial factors in assessing clinical outcomes. For this purpose, we used the Tegner activity score and Lysholm score. We found a significant improvement in Lysholm activity scores postoperatively (p<0.05). Özdemir et al.[15] found similar results following rehabilitation of patients undergoing ACL reconstruction with the bone-patellar tendon-bone graft. Preoperative and postoperative Tegner activity scores were not significantly different in our patients, but 63.2% of the patients reached preoperative Tegner scores. The majority of the patients were non-athletes and did sports for recreational activity, so their motivation for returning to preoperative activity might be low. Some of them expressed that they were satisfied with their postoperative activity levels and would prefer not to return to sports activities because of risk for reinjures. Six patients were athletes and five of them reached their preinjury Tegner scores. Most studies reported improved Lysholm scores with the PT graft;[16-20] however, it was also emphasized that, regardless of the graft source, patients usually could not reach their preoperative activity levels.[18-20]

Strength deficits of the knee flexors and extensors have been demonstrated in both ACL-deficient and ACL-reconstructed patients.[20-24] Most studies showed that loss of quadriceps strength was more than that of the hamstring following surgery, especially when the PT graft was used,[21-23] and a significant correlation was found between the quadriceps strength and functional stability.[24] In our study, loss of quadriceps strength was significant only at 60°/sec angular velocity in the operated limb, but this decrease was not as much as other studies. Despite this difference, the muscle strength of the operated limb reached at least 85% of the uninvolved side. It is also known that a 10% difference between the strengths of two legs may be present in normal individuals in relation to the dominant side. Quadriceps strength measurements were similar in both legs at 180°/sec and 240°/sec angular velocities, showing that the strength of the operated extremity reached that of the intact extremity. These higher speeds have been demonstrated to reflect the athletic activity more accurately and to be more functional.[25]

Co-contraction of the quadriceps and hamstring muscles is frequently altered in ACL deficiency. Increased hamstring activity has been reported in many ACL-deficient patients. Theoretically, this increase in hamstring activity would result in decreases in shearing forces on the tibia, thereby minimizing the strains on the ACL graft. Hamstring training also seems to provide distinct benefits in terms of functional improvement, and is recommended in rehabilitation.[26,27] In our rehabilitation program, we strengthened the hamstring muscles as well as the quadriceps. We aimed to increase the hamstring-quadriceps ratio for knee stability and to avoid reinjury of the knee. The ratios of flexion/extension muscle strength were significantly higher in the operated limbs after our rehabilitation program.

The ACL has two complementary functions: proprioceptive and mechanical. In previous years, the emphasis in ACL reconstruction was placed on how to reconstruct a mechanically strong ligament. However, evidence for the proprioceptive function of the ACL derived from histological studies has shown the existence of several types of mechanoreceptors in the human ACL. Thus, impaired proprioceptive feedback may be expected in ACL tears.[28] There are several studies on proprioception in knees with ruptured ACL, reporting decreased proprioception.[29,30] Proprioception is assessed by measuring kinesthetic sensibility and joint position sensibility which are perception of joint motion and joint position, respectively. Kinesthesia is assessed by measuring the threshold to detection of passive motion (TTDPM), while joint position sense is assessed by measuring reproduction of passive positioning (RPP) and active positioning (RAP). Both kinesthesia and position sense have been assessed in several clinical studies. Following ACL injuries, TTDPM and RPP can be used to assess proprioception. When tested at slow angular velocities (0.5-2.5°/sec), the TTDPM is thought to selectively stimulate Ruffini- or Golgi-type mechanoreceptors and, because the test is performed passively, it is believed to maximally stimulate joint receptors while minimally stimulating muscle receptors. Thus, TTDPM is often chosen to assess afferent activity with elimination of muscle activity following ligament pathologies.[8] Passive positioning also maximally stimulates slowly adapting ligamentous and capsular receptors. We used RAP to assess the proprioceptive function in ACL-reconstructed knees. We preferred this method because reproductions are done actively using muscular contractions of muscle groups during RAP, thus enabling elicitation of input from the musculotendinous receptors as well.[31] Although it is usually performed at slow speeds, RAP stimulates both joint and muscle receptors and provides a more functional assessment of the afferent pathways.[8] Moreover, it is a practical and easy method for patients in testing joint position. Reflex activity of the hamstring muscles following direct stresses on the ACL is a critical factor in dynamic knee stability.[27] After ACL reconstruction, one of our major aims is to enhance dynamic knee stability by neuromuscular training of the hamstring muscles. For this reason, evaluation of both muscle and joint receptors with RAP gains importance. Some studies concluded that proprioception might be restored to an equal level compared to the uninjured contralateral limb or controls.[30,32,33] Proprioception correlates well with both function and patient satisfaction.[20,34] In contrast, some authors reported persistent impairment of proprioception.[30,35] Anders et al.[35] evaluated proprioception in patients undergoing ACL reconstruction with a PT graft and found deficiencies in the RAP test. These deficits were very small but were still detectable.[35] In our study, there were no significant differences at all angles between the operated and uninjured limbs in the evaluation of proprioception by the RAP test. These results may be attributed to our rehabilitation program, which includes proprioceptive exercises.

Before surgery, the Lachman test and anterior drawer test were positive in all the patients. After surgery, the Lachman test was negative in most of the patients (84.2%), and only six patients (15.8%) had grade 1 laxity. We could not evaluate knee stability with an arthrometer due to unavailability; therefore, we did not evaluate the relationship between static stability and other outcome parameters. This might be a limitation of our study. However, knee laxity does not correlate with functional results in most studies,[36-38] so static measurements may be insufficient to predict the dynamic stability of the knee.[36,37]

As clinical tests including strength testing and laxity measurements do not correlate well with functional ability in all cases, functional tests have been developed to help evaluate surgical and therapeutic outcomes and the patients' readiness to return to unrestricted activity. The most commonly used tests are the single hop for distance, triple hop for distance, and 6-m hop for time.[39]

It has been reported that achievement of more than 90% of knee function (including the single-leg hop test) compared with the uninjured side can be regarded as a successful return to preinjury activity levels in patients with ACL-deficient knees. If a difference of more than 10% exists between the functions of the involved and non-involved legs following ACL reconstruction, then the results are accepted as unsatisfactory for both hop and strength tests.[40] In our study, functional tests showed that 68.4% of the patients had at least 85% performance in the injured extremity compared to the uninjured side. Katayama et al.[29] evaluated functional performance of patients and found that the distances of one-leg hop and vertical jump tests were markedly reduced on the injured side compared with that of the intact side.

Decreased sensation, lower-extremity muscle weakness, and damage to receptors can affect standing balance. Standing balance is often part of the physical evaluation of lower-limb neuromuscular function. Studies on single-leg standing balance demonstrated that the mean center of gravity was similar for dominant and nondominant legs.[41,42] In our study, there was no significant difference in static balance measurements between the involved and uninvolved sides.

Roberts et al.[7] evaluated 36 patients with ACL deficiency with laxity test, proprioception test, single-leg hop test, and muscular peak torque measurements and found a significant relationship between the distance of the single-leg hop test and proprioception. They concluded that a higher proprioceptive threshold value, increased difference of laxity in the anterior drawer test, and poorer strength were correlated with functional insufficiency in ACL-deficient patients.

Reconstruction of the ACL with a PT graft is accused of having some disadvantages such as quadriceps weakness, donor tissue morbidity, decreased proprioception, and functional impairment. In our study group, 52.6% had hypoesthesia at the donor site and 39.5% had anterior knee pain. There were no proprioceptive and balance deficits associated with the modified accelerated rehabilitation program, and the results of subjective functional tests, activity levels, and functional tests representing the dynamic stability of the knee were satisfactory. The quadriceps strength was found insufficient only at the angular velocity of 60°/sec. The contribution of this strength deficit to postoperative functional ability and predisposition to future injuries is not clear. Postoperative rehabilitation protocols can be modified to reduce this strength deficit with inclusion of velocity-specific exercises. In conclusion, the modified accelerated rehabilitation program after ACL reconstruction with a PT graft yielded satisfactory clinical results in returning to daily and sportive activities through restoration of the dynamic and static stability of the knee.

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