

Effect of Proprioceptive Rehabilitation on Postural Control Following Anterior Cruciate Ligament Reconstruction

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Abstract. [Purpose] The aim of this study was to determine the functional level of activity and postural control after rehabilitation of anterior cruciate ligament reconstructed knees and compare them with non-operated limbs and healthy limbs in control subjects. [Subjects] Twenty-seven patients participated in the study: 17 had undergone reconstruction with a bone-patellar tendon-bone and 10 with a semitendinosus graft technique. The same rehabilitation protocol was used for all of the patients. Besides the patients, 18 healthy volunteers participated as a control group. [Methods] Both groups were tested for one-leg standing (eyes open and closed), static (eyes open and closed) and dynamic postural control on The Kinesthetic Ability Trainer-KAT 2000 (OWM Medical, Carlsbad, California, USA) at the 3, 6 and 12 month post-operation. Functional outcomes of the rehabilitation were evaluated by Lysholm scoring. [Results] There were no significant differences for the eyes open static stabilometry test between operated and non-operated limbs of the patients. On the other hand, there were statistically significant differences for the closed eyes static balance test between the operated and non-operated limbs at 3 and 6 months after surgery. There were significant differences for the eyes open static balance test between the 3rd and 6th, and 6th and 12th months and for the eyes closed test of non-operated limbs between the same months as well. No statistically significant differences were noted in the dynamic balance tests between the patients and the control group. Lysholm scores of the patients obtained at 6 and 12th months after surgery were significantly better than those at 3 months after surgery. Different operation techniques revealed no significant differences in any test performed at any time. [Conclusions] Performing a postoperative sportive rehabilitation including specific proprioceptive training sessions has positive effects both on clinical status and postural control of the patients.

Key words: Anterior cruciate ligament, Rehabilitation, Postural control

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INTRODUCTION

The anterior cruciate ligament (ACL) is the most frequently injured knee ligament, accounting for about 50% of all ligament injuries¹⁻³⁾. Patients with tears of the ACL often experience knee instability⁴⁻⁶⁾ which may produce progressive functional changes and damage to other joint structures, and may also

affect daily life activities²⁾. Athletes often find it difficult to return to full function after ACL injury and surgery is frequently indicated⁷⁾.

The visual, vestibular and somatosensory systems contribute afferent information to the central nervous system (CNS) regarding body position and balance⁸⁾. This neural input is integrated by the CNS to generate a motor response. Sensory

receptors are present in the skin, muscles, joints, ligaments and tendons⁸⁻¹¹). Since a ligament injury causes a disturbance in the somatosensory system it may affect the central programs and motor response¹).

Proprioceptive receptors normally found in the ACL^{2,12}), are the first elements of the protective reflex arc that control the contraction of the thigh muscles, confirming the opinion that the ACL plays a primary role among all the sources of proprioceptive information from the knee⁶). Although mechanoreceptors in the ACL seem to play an important role in proprioceptive function, Adachi et al. found no correlation between the number of mechanoreceptors in the ACL and proprioceptive function⁹).

Somatosensory information from the lower limb contributes to postural control, and reports of decreased knee proprioception have prompted researchers to study the effects of ACL injury through measuring the standing balance^{13,14}). Various measures of force platform centre of pressure data have been used to suggest that postural control is compromised in patients with ACL-deficient knees and in patients who have undergone reconstruction¹⁵).

Several studies have shown that even after ACL rupture, patients display decreased proprioception^{4,5,16}) and to some extent this remains even after reconstruction^{2,6,17}). It has also been shown that patient satisfaction does not correlate well with knee joint stability following ACL reconstruction, but rather with the residual level of proprioception. This suggests that the ability to provide functional knee joint stability through neuromuscular control is an important factor after ACL reconstruction¹⁴).

Recently, reconstructive techniques have been refined to achieve better stabilization of the knee joint and, consequently, better functional recovery²). Despite these efforts, functional recovery of the knee after ACL surgery is still unsatisfactory in many cases. It has been suggested that the lack of full recovery of knee function after ACL reconstruction is due to sensory and motor behaviour deficits²).

Although sensory and motor changes have been described in individuals with ACL lesions¹⁸), such changes have not been well described in individuals who have undergone ACL reconstruction. After ACL reconstruction, these sensory and motor

changes are more variable and, therefore, more difficult to describe²).

Proprioceptive afferent neural input is also important in functional control during sport activities. It has been suggested that, after surgery, the ability to perform functional activities and balance may be decreased, and deficits have been found in the muscular and sensory processes after reconstructive surgery⁷). Muscular control⁴), gait, functional activities⁷) and proprioception^{6,12}), have been evaluated after ACL reconstruction, while the effect of dynamic postural stability has been minimally evaluated¹⁹). Rehabilitation programmes formerly focused mainly on restoration of muscle strength, but during the last 10 years, the sensory function of ligaments in relation to functional joint stability has been regarded as important in rehabilitation after a ligament injury and reconstruction¹).

The aim of this study was to determine the functional level of activity and postural control after rehabilitation of anterior cruciate ligament reconstructed knees and compare them with non-operated limbs and healthy limbs in control subjects.

METHODS

Between 2005–2006, 27 patients underwent ACL reconstruction at the University Hospital of Ankara, Cebeci Campus in Turkey. The study group consisted of 27 patients: 17 had undergone a reconstruction with a bone-patellar tendon-bone and 10 with a semitendinosus graft technique. The same rehabilitation protocol was carried out for all the patients. Patients with the semitendinous graft followed the program with 2 weeks of postponement after full weight-bearing at the end of sixth week. The study group consisted of 5 women and 22 men, with a mean age of 26.52 years. Surgical reconstruction had been performed on 15 right knees and 12 left knees. All subjects were involved in sports activities (18 professionals and 9 amateurs). The period of time from injury to reconstruction was 1.96 ± 0.85 years. Since all the patients consulted postoperatively, preoperative measurements could not be performed. In the 3rd, 6th and 12th months after surgery, all the subjects were clinically evaluated by the same clinician and tested for static and dynamic postural control, Lysholm scoring and single-leg standing tests were

Table 1. Mean and standard deviation of patients' (both male and female subjects) age, sex, height, weight and dominant side, knee injury side, type of graft, and sport

	Patients			Controls		
	Men	Women	Total	Men	Women	Total
Sex	22	5	27	14	4	18
Age	27.31 ± 7.68	23.00 ± 10.63	26.51 ± 8.24	20.92 ± 3.75	21.00 ± 4.24	20.88 ± 3.59
Height	177.40 ± 7.71	171.20 ± 8.07	176.75 ± 8.0	178.92 ± 8.52	168.5 ± 4.43	176.61 ± 8.63
Weight	77.72 ± 11.05	62.4 ± 7.12	74.88 ± 11.97	74.92 ± 7.95	58.00 ± 6.16	71.16 ± 10.09
Dominant side:						
Right	21	5	26	14	4	18
Left	1	0	1	0	0	0
Injured side:						
Right	13	2	19			
Left	9	3	22			
Sport:						
Football	9	0	9	7		7
Basketball	3	2	5	2	2	4
Volley Ball	1	1	2	2	1	3
Hand Ball	2	1	3		1	1
Others	7	1	8	3		3
Graft type:						
Patellar t.	16	1	17			
Hamstring	6	4	10			

performed as well. The control group consisted of 18 subjects with no prior history of significant trauma to the lower extremity and they were clinically evaluated by the same physician. Their mean age was 20.94 years and this group consisted of 14 men and 4 women. All subjects were involved in recreative sports activities. There were no significant differences among the groups in age, height or weight (Table 1). All tests were performed only once in the control group. The control group called for tests at 6 and 12 months, because the literature ensured us that learning effects usually cease 3 weeks after measurement.

Patients who met the following criteria were participated in the study: (1) only one surgery for tear of the ACL that did not include a concomitant tear of the posterior cruciate ligament; (2) no evidence of collateral ligament repair at the time of surgery; (3) no history of surgery or traumatic injury to the contralateral knee; (4) no history of surgery or traumatic injury of the ankle joint; and (5) no history of surgery or traumatic injury to either hip joint. The subjects were clinically evaluated before participating in testing. None of the patients and controls had instability or additional lesions during the study period. All subjects underwent a

specific rehabilitation programme at the Ankara University School of Medicine, Department of Sports Medicine for three months and a home-based programme before being allowed to participate in sports activities.

Proprioceptive rehabilitation began just after ACL reconstruction. The proprioceptive rehabilitation protocol was the same for all patients and consisted of routine items such as improving range of motion, stretching the shortened muscles, improving flexibility and strength, proprioceptive and balance training using a mini trampoline, with open and closed eyes in a two-leg stance and then single-leg stance using the injured limb. Functional electrical stimulation to the vastus medialis obliquus was applied to retrain this muscle on the injured limb. The postoperative programme consisted of passive full extension and active flexion over a range of 0–120 degrees from the third postoperative day. The patients were allowed minimal partial weight-bearing without bracing in the first week. At the same time isometric and closed chain proprioceptive exercises were performed, as well as active and passive full range of motion exercises. Full weight-bearing was allowed by the end of the 6th week. Running and

quadriceps muscle resistive exercises started after the 10th week for patellar tendon graft patients, whereas semitendinosus graft patients started by the end of 12th week. Cutting and lateral running were allowed by the end of 6 months for bone-patellar tendon-bone and 8 months for semitendinosus graft patients. This standard protocol was applied to each patient under the supervision of one physiotherapist.

One physiotherapist who had performed the same tests for a previous study conducted the testing procedures.

The one-leg standing test evaluates a subject's ability to keep balance while standing on one leg. The subject is asked to stand on one leg for one minute with eyes open. If the subject completes this test without any fault for one minute the test is ended. Then the same test is repeated with the eyes closed to exclude visual perception. During the test the subjects are requested to stand on one leg while the other leg is raised by flexing from the knee with the arms crossed at the chest²⁰.

Postural control: Postural control evaluation were conducted by using the Kinesthetic Ability Trainer-KAT 2000 (OEM Medical, Carlsbad, Calif., USA) with Windows-supported software to establish two types of balance indices, a so-called static balance index and a dynamic index. The KAT 2000 is a balance platform designed for training and functional testing of balance ability. The KAT 2000 consists of a movable platform which is supported at its central point by a small pivot. The stability of the platform is controlled by varying the pressure in a circular pneumatic cushion resting between the platform and the base of unit. The support platform of the KAT 2000 can be placed at 10 levels. The resistance of the foot platform changes at each level. When inflated, the platform is stabilized, and when deflated, the platform becomes extremely unstable. We used the 6th level. A tilt sensor on the front of the platform is connected to a computer which registers the deviation of the platform from the reference position 18.2 times in every second during a test period. The distance from the centre of the platform to the reference position is measured at every registration; from the summation of these distances, a balance index score can be calculated²¹.

In determining the static balance index the subject has the task of keeping the platform in a neutral position. For visual checking he sees a circular

target on a monitor with a cross, which, if the platform is moved to one side, moves from the centre of the circular target accordingly. This moving target on the monitor, therefore, shows the deviation of the subject's position from the neutral position. The closer the point is to the centre, the more the platform is in the neutral position.

The test may also be conducted with eyes closed. To execute the eyes closed test, the subject looks at a cross sign drawn on the wall 65 cm away from the subject until he/she balances himself/herself on the testing device. Then, the subject is asked to close the eyes and try to keep the balance. During all the tests the subject stands on one leg while the other leg is raised by flexing from the knee with the arms are crossed at the chest.

The static balance index is determined according to the degree of deviation and dwell time (amount of time spent in one of the quadrants) in one of the quadrants. For the four quadrants the equipment calculates separate balance indices, the sum of which produces the static total balance index. A low balance index indicates good conformity with the neutral position and therefore good stabilization capability in the knee joint^{21,22}.

To determine the dynamic balance index, the subject has the task of tracking a point orbiting the visible circular target on the monitor as accurately as possible using the position cross, which can be controlled by the platform. The more accurate the conformity is between the cross and the orbiting point, the lower the dynamic balance index^{21,22}.

For each test series the KAT 2000 test was performed three times for the reconstructed and non-reconstructed limbs. Static balance tests were conducted both with eyes open and closed conditions. Dynamic balance tests were performed by standing on both legs with eyes open three times as well. The best score was recorded. All test procedures were conducted by one experienced physiotherapist.

Lysholm knee scoring²³) was performed for the patients to determine their functional status at 3, 6 and 12 months after surgery.

Statistical analysis

All data comparing postural control function and one-leg standing between test subjects and controls was performed using the Mann-Whitney test. All data comparing postural control function and one-leg standing among 3, 6 and 12 months after surgery were performed using the Friedman test.

Table 2. One-leg standing test mean scores in seconds

Group		Eyes open			Eyes closed		
		3 months	6 months	12 months	3 months	6 months	12 months
Patients	ACLR side	53.48 ± 10.42 ^b	58.14 ± 9.62	60.00 ± 0.00	21.01 ± 18.04 ^d	38.59 ± 20.59	39.40 ± 22.25
	Uninvolved side	54.22 ± 10.94 ^a	59.55 ± 2.31	60.00 ± 0.00	19.33 ± 16.49 ^c	38.41 ± 20.82	36.30 ± 21.48
Controls	Dominant side	60.00 ± 0.00 ^{a,b}	60.00 ± 0.00	60.00 ± 0.00	43.22 ± 16.37 ^{c,d}	43.22 ± 16.37	43.22 ± 16.37

^{a,b}: $p < 0.05$, ^{c,d}: $p < 0.001$.

Table 3. Mean static balance scores obtained by KAT 2000

Group		Eyes open			Eyes closed		
		3 months	6 months	12 months	3 months	6 months	12 months
Patients	ACLR side	320.48 ± 173.51	244.44 ± 100.10	349.22 ± 155.00	691.37 ± 411.39	560.77 ± 225.60 ^a	773.85 ± 411.34
	Uninvolved side	366.70 ± 200.36	264.59 ± 110.12	374.25 ± 176.12	798.70 ± 435.76	632.22 ± 205.32 ^a	795.89 ± 330.84
Controls	Dominant side	355.70 ± 200.35			817.16 ± 430.44 ^a		

^a: $p < 0.05$.

Spearman's correlation coefficient ($p < 0.05$) was used to determine whether there were relationships between outcome measurements and postural control scores.

RESULTS

There were no significant differences between the operated and the non-operated limbs in the one-leg standing tests at 3, 6 and 12 months after surgery respectively, with both eyes open or closed.

There was a significant difference between the 3rd month values of the control group and patients, while no significant differences were detected between those of the 6th and 12th months ($p < 0.05$). When one-leg standing scores of patients were compared significant differences were found between the 3rd month values and the 6th and 12th month values both for eyes open and closed ($p < 0.001$) (Table 2).

The static balance test scores revealed no significant differences between the operated and nonoperated limbs when performed with eyes open. On the other hand, the 6th month scores of the operated limbs were significantly lower than the 3rd month scores in the eyes closed static balance test ($p < 0.05$).

Control group comparisons revealed no significant differences in the eyes open static test, whereas the operated limbs eyes closed scores at the 6th month were significantly lower than the control

Table 4. Mean dynamic balance scores obtained by KAT 2000

Group	3 months	6 months	12 months
Patients	1326.29 ± 243.65	326.85 ± 240.65 ^a	1449.07 ± 272.01 ^a
Controls	1341.50 ± 237.03		

^a: $p < 0.05$.

Table 5. Mean Lysholm knee scoring results of the patients

	3 months	6 months	12 months
Patients	84.14 ± 9.80 ^{a,b}	90.40 ± 8.73 ^a	90.44 ± 9.90 ^b

^{a,b}: $p < 0.05$.

group eyes closed scores ($p < 0.05$).

Eyes closed tests also showed significant differences for both operated and non-operated limbs between the 3rd and 6th months, and the 6th and 12th month results (Table 3).

The results of the dynamic balance test revealed no significant differences among the groups, however, a significant increase was noted between the 6th and 12th months in the patients group (Table 4).

There was a significant difference between the 3rd and 6th months, and between the 3rd and 12th months in the Lysholm knee scores of the patients (Table 5).

We found no correlations between Lysholm knee score and one-leg standing and static-dynamic balance index results of patients.

The comparison of patellar tendon-bone-tendon

and hamstring grafts did not reveal any significant differences.

DISCUSSION

Surgical reconstruction of the anterior cruciate ligament (ACL) may reduce, but it does not always eliminate knee and body instability because of a persisting proprioceptive deficit²⁴). The main goal of our study was to evaluate changes in postural control and its effects on the functional status of patients who had undergone unilateral ACL reconstruction (ACLR). Our primary finding was that after ACLR, patients did not have deficits in postural stability compared to the control group. Decreased joint proprioception has been shown by several authors^{4,5,16,25,26}). On the other hand, some researchers have reported that impaired postural control of ACL deficient patients significantly improved following reconstruction^{2,17,19}) while others have failed to find a significant difference^{5,12,27-29}).

Most previous studies have focused on sensory and motor functioning after ACL lesion, and some of them have investigated the motor functioning after reconstruction^{2,5,17,19,27-29}). No studies, however, have assessed the postural control of ACLR patients in a long-term follow-up.

Postural stability studies on ACLR patients are very few¹⁹). Our findings are consistent with those of Harrison et al.³) who found no significant differences between the ACL reconstructed and uninvolved knees during eyes open testing on the Chatter Balance System (Chatter Corp. Chattanooga, TN). In addition, Mattacola et al.⁷) found no differences between ACLR and control subjects in single-limb and bilateral stability index scores. Similarly, Risberg et al.¹²) and Hopper et al.²⁹) found no significant differences in proprioception between ACLR and uninvolved knees, and between ACLR patients who had undergone an operation at least one year ago and a healthy control group. Hoffman et al.¹⁹) reported increased dynamic postural control in an ACLR group compared to a control group, however, they measured postural stability only in the sagittal direction whereas we assessed postural stability in both the sagittal and frontal planes.

Bonfim et al.²) assessed sensory deficits and their effects on proprioceptive and motor function in patients who had undergone unilateral ACLR.

They found that a reconstructed knee showed decreased joint position perception, a higher threshold for detection of passive knee motion, longer latency of hamstring muscles and decreased performance in postural control. This, they explained, was due to a lack of proprioceptive information arising from the ACL lesion and/or substitution of ACL by the graft. Although most researchers have suggested that reconstruction of a mechanical restraint (ACL graft) is believed to have a significantly positive impact on early and progressive improvement in proprioception²⁶), Valerini et al.⁶) stated that arthroscopic reconstruction of ligaments did not improve knee proprioception or somatosensory central conduction.

Denti et al.¹⁷) demonstrated significant differences in postural control functions of ACLR knees 5-8 years after the index surgery and the knees of normal control subjects. In the present study, we found no significant differences in the eyes open static balance test of patients and control subjects, while we observed significantly different scores when the eyes were closed 6 months after the operation. Visual sensory input constitutes a part of the sensorimotor system used in postural control³⁰). When there are no visual inputs, keeping the balance is more difficult. Muscle weakness due to atrophy developing following surgery, and declining somatosensory function possibly due to corruption of the receptors affect balance while standing up. Interruption of visual input results in increased body oscillation and decreased postural control. We found significant improvements in the eyes closed one-leg standing results of ACLR sides following the rehabilitation, whereas the improvements obtained for the uninvolved limbs revealed no significant improvement. The significant improvement on the injured side might have resulted from intensive sports rehabilitation and neuromuscular exercises which focused on the injured extremity.

Reider et al.²⁶) evaluated changes in proprioception from pre-operative to 6 months postoperative follow-up. They showed significant improvement in both injured and contralateral knees after ACLR but they found no significant differences in the controls at the 6-month follow-up. Henriksson et al.³⁰) found similar improvements in postoperatively rehabilitated ACLR patients, except for muscle reaction time and latency. They

concluded that rehabilitation, with proprioceptive and agility training was important for restoring functional stability in the ACL reconstructed knee. We did not find any significant differences between the patients and control subjects for the eyes-open static and dynamic postural control scores. On the other hand, we found significant differences at the 6th month eyes closed static postural control status of the operated limbs. However, our evaluations did not include preoperative proprioceptive evaluations of the patients.

Our postoperative rehabilitation protocol did contain specific proprioceptive training sessions. Therefore, we were not able to differentiate whether the postoperative improvements in postural control were due to the result of surgery itself or the postoperative rehabilitation programme. Proprioceptive training of the ankles and the hips should thus be considered as an important part in overall rehabilitation after ACLR surgery to improve the compensatory mechanisms and restore the pattern for correction.

Recently, Valeriani et al.⁶⁾ stated that permanent changes may develop in proprioception following ACL rupture. They suggested that better postoperative outcomes were expected for patients who did not develop these proprioceptive deficits.

Most of the patients in our study had chronic ACL injuries, with a mean time from injury to surgery of 17 months. The differences in time of injury and surgery might have explained the inconsistency of the results when compared to outcomes reported in the literature.

This investigation had some limitations. Factors such as activity levels, type of work and degree of fitness were not quantified in patients or controls. All of these factors, including the interval between the index surgery and the evaluation, may have affected the results. Finally, one must assess the relevance of the test method to normal physiological activity. As opposed to quasi-dynamic methods, such as replication of position or detection of motion, the KAT 2000 addresses dynamic stability in static tests and forces the subject to perform dynamic work in performing the dynamic tests. However, this system does not assess activities involving acceleration and deceleration, or rapid directional changes which are characteristic of most physiological activities¹⁷⁾.

Lysholm scores were found to be significantly improved over the 3rd month at the 6th month

evaluation. On the other hand, no significant improvement was noted between the 6th month and 12th month evaluations. Our rehabilitation programme continued until the 6th month. The 6th to 12th month programme was conducted as a home-based exercise programme. Lack of further improvement might have resulted either from the uncontrolled home-based exercise programme or the relatively good scores that had already been obtained by the 6th month.

There were no correlations between postural control scores and the Lysholm knee scoring in this study. Similarly, Reider et al.²⁶⁾ found no correlation between proprioception and Lysholm scores and/or knee laxity levels. On the other hand, Risberg et al.¹²⁾ found moderate to low correlations between proprioception and other outcome measurements including The Knee Osteoarthritis Outcome Score, Cincinnati knee score, and two functional knee tests.

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