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ORIGINAL STUDY

Factors affecting isokinetic muscle strength before and after anterior cruciate ligament reconstruction

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The purpose of this study was to evaluate the factors affecting muscle strength of ACL-deficient knees before and after ACL reconstruction. The study included 122 male patients who underwent primary ACL reconstruction with a bone-patellar tendon-bone autograft. Preoperative loss and change in muscle strength in both extensor and flexor muscle groups after ACL reconstruction were calculated separately at 60º/sec and 180º/sec angular velocities. We evaluated the effect of surgical delay on the preoperative deficit and on its change after surgery. Muscle strength change after ACL reconstruction was also evaluated in relation to patient compliance to treatment. The longer the delay of ACL reconstruction the more the muscle strength deficit of flexor and extensor muscles increased. In the ACL deficient knees with high strength deficit, improvement in muscle strength was higher after ACL reconstruction for both muscle groups. When delay of ACL reconstruction was short and the patient was compliant to treatment, flexor muscle strength recovery was early. Shortening the delay to reconstruction had a positive influence on muscle strength after ACL reconstruction when preoperative muscle strength deficit was high.

Keywords : isokinetic strength ; peak torque ; ACL-deficient ; ACL-reconstructed.

INTRODUCTION

Isokinetic extensor and flexor muscle strength measurements before and after anterior cruciate ligament (ACL) reconstruction have concluded to varying results (*4,5,7,12,13,16-18,20-23,27,29*). The reported extensor muscle strength deficit in ACL-deficient knees as compared to the other knee, varied from 7.3% to 18% (*7,11,12,15-17,22,25,26,29*). Some authors find no deficit in flexor muscle strength (*16,17,22,29*), others report variable levels of deficit in flexor muscle strength (*7,11,25,26*) in the ACL-deficient knee. It is generally accepted that an extensor muscle strength deficit persists after reconstruction (*7,12,15-18,21,22,29*). In these studies, isokinetic muscle strength measurements were performed at different angular velocities on different postoperative days and therefore varying muscle strength evaluations are expected. Other factors such as gender, rehabilitation program, selection of graft and type of dynamometer used for isokinetic

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measurements can also lead to varying results (7-9, 12,15,20,22,27). Even if the above-mentioned factors are standardized, patient-dependent factors can also lead to varying results. Return to near normal muscle strength may be important for a satisfactory outcome (13,17,26,28). The aim of the present study is to evaluate the factors affecting extensor and flexor muscle strength of the ACL-deficient knee before and after primary ACL reconstruction in male patients submitted to one type of surgery, one graft type, and a fixed rehabilitation program. It was hypothesized that muscle strength would be affected by the timing of treatment, preoperative muscle strength deficit and patient compliance to treatment.

PATIENTS AND METHODS

A total of 167 male patients underwent primary ACL reconstruction with a BPTB autograft. Three patients with bilateral ACL ruptures were excluded. An additional 19 patients were eliminated because of missing muscle strength measurements before or after ACL reconstruction. Another 19 patients, who had previously undergone arthroscopy or had received treatment for associated bone or other ligament injuries of involved or uninvolved knee were also excluded. To calculate the surgical delay or time from injury (TFI) a history of a definite single injury initiating symptoms was needed. Four patients had no clear history of a single initial traumatic episode and were excluded. In total, based on these criteria, 45 patients were excluded and 122 patients were left for a retrospective evaluation with prospectively collected data.

These patients underwent arthroscopically assisted primary ACL reconstruction with a bone-patellar tendon-bone (BPTB) autograft to repair a complete ACL rupture, a diagnosis based on clinical evaluation and confirmed by arthroscopic examination. All reconstructions were performed on military male patients at the Military Hospital by one surgeon, using the same surgical technique for all patients. In all patients, reconstruction with BPTB autograft was performed under tourniquet control with a single incision technique and interference screws. For each patient, age, clinical history, and TFI were recorded. The mean age of the patients was 29.1 ± 7.9 years (range : 19 to 46). Written informed consent was obtained from all subjects. Local ethical approval (9100-69-06) for this study was granted by the ethics committee of our hospital.

The patients were grouped according to the surgical delay (time from injury : TFI) as in another of our studies (30). The acute period ended 6 weeks after the initial trauma, a lesion was subchronic between 6 weeks to 12 months and chronic 12 months after injury.

Postoperative rehabilitation program

All patients were rehabilitated according to Shelbourne's (24) "accelerated" program beginning the first postoperative day. This program emphasizes early restoration of full extension and flexion and allows weight bearing as tolerated. Isokinetic measurements and rehabilitation were done at the same center by the same physical therapist blinded to the study. The uninvolved knee of all patients was also included in a standard program of isometric and isokinetic exercises designed to increase strength and endurance of flexors and extensors.

Isokinetic measurements

Isokinetic muscle strength (IMS) of extensor and flexor muscles were measured by the "Cybex Norm Testing and Rehabilitation System®" (Cybex Int., Inc, Ronkonkoma, NY) before and after ACL reconstruction at the most routinely used angular velocities (60°/sec and 180°/sec). Comparable data are abundant (7,9,11,13,18,21, 23,26,27). Muscle strength deficits tend to be magnified under higher resistance at lower angular velocities (60°/sec). At 180°/sec angular velocity isokinetic rehabilitation and training can be performed earlier and results parallel capability to daily function (1,3,28).

The preoperative isokinetic measurement used as a reference was performed in the week preceding the operation. Patients in the acute period had regained full knee range of motion, no longer had knee swelling, and walked with a normal gait. Postoperative IMS measurements were performed between 18 and 24 weeks postoperatively following the patient's return to daily physical and training activities of his occupation. Muscle strength and peak torque (PT) values (Nm) (highest value of torque, regardless of repetition) for each velocity of extensor and flexor muscles of both knees were recorded. Normalizing peak torque values of each subject in accordance with body-mass allowed valid inter-subject comparison (2,3,6,19).

The muscle strength deficit (MSD) before ACL reconstruction was calculated and muscle strength change (MSC) after ACL reconstruction was calculated.

$$\text{MSD (\%)} = \frac{\text{Before PT value}_{\text{uninvolved knee}} - \text{Before PT value}_{\text{involved knee}}}{\text{Before PT value}_{\text{uninvolved knee}}} \times 100$$

$$\text{MSC (\%)} = \frac{\text{After PT value}_{\text{involved knee}} - \text{Before PT value}_{\text{involved knee}}}{\text{Before PT value}_{\text{uninvolved knee}}} \times 100$$

Fig. 1. — Muscle strength deficit and change were calculated for knee flexor and extensor muscles at 60 and 180°/sec angular velocities. (MSD : muscle strength deficit ; MSC : muscle strength change ; before : before ACL reconstruction ; after : after ACL reconstruction).

Figure 1 shows the formula used to calculate muscle strength deficit and percentages of change for both extensor and flexor muscles and at both angular velocities. As a reference the preoperative muscle strength measurements were noted for the uninvolved knee for the same muscle groups at the same angular velocity.

Patients were grouped according to their preoperative muscle strength deficit and separately for each muscle group and each angular velocity. Group I contains patients with a strength deficit of 25% or more in their involved knee as compared to the uninvolved knee. In Group II, the strength deficit was between 10% and 25%. In Group III, the strength deficit of the involved knee was 10% or less (Fig. 2).

Muscle strength measurements of the uninvolved knee were used to evaluate factors affecting muscle strength change after ACL reconstruction. Patients whose post-rehabilitation peak torque value of the uninvolved knee was higher for both extensor and flexor muscles at one or both of the angular velocities, when compared with preoperative values were listed under group A : these patients were considered as compliant to medical recommendations and were postoperatively willing to do what they were asked to do at an optimal level during physical therapy. Group B contained patients with no improvement in their post-rehabilitation peak torque values for either or both muscle groups at both angular velocities.

Statistical Evaluation

By using the NCSS-PASS statistical software, the required sample size was calculated as 120 with a power of 0.93 while alpha = 0.05. Data analysis was performed using the SPSS for Windows version 11.5 statistical software program. The Kolmogorov-Smirnov test was used to test normality for all continuous variables. The Kruskal-Wallis (category > 2 and continuous variables with non-normal distribution), Mann-Whitney U (category = 2 and continuous variables with non-normal distribution), and one way ANOVA (category > 2 and continuous variables with normal distributions) were used in the statistical evaluation. $P < 0.05$ was considered as statistically significant.

RESULTS

Demographic data for all patients are given in table I. There were no adverse events following surgery or postoperative rehabilitation and isokinetic testing procedures. The mean ages of patients were statistically similar in TFI groups ($p = 0.428$) *(ANOVA)*. Patient groups according to strength deficits of extensor and flexor muscles before ACL reconstruction at 60 and 180°/sec are presented in Figure 2.

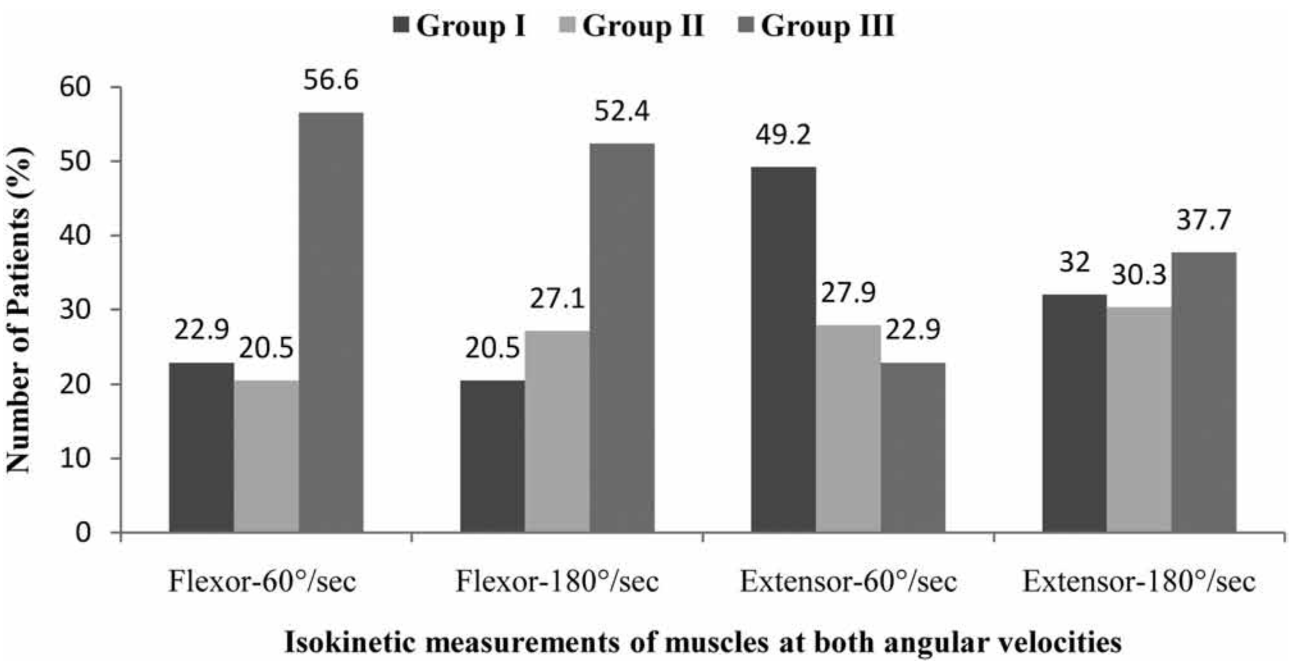

Fig. 2. — Patient grouping and distribution according to strength deficits of extensor and flexor muscles at both angular velocities (flexor : flexor muscle ; extensor : extensor muscle ; Group I : patients with a MSD of 25.0% or more ; Group II : MSD was between 25.0% and 10.0% ; Group III : MSD was 10.0% or less).

Table I. — Demographic data of all patients included in the study

Number of patients	122
Mean time from injury (TFI) (months)	16.3 ± 18.6 (3 weeks to 90 months)
Distribution of patients according to TFI groups (%)	
Acute	27.9
Subchronic	31.2
Chronic	40.9
Mean strength deficit before ACL reconstruction (%)	
Flexor muscles (60 and 180°/sec)	8.4 ± 23.0 and 8.6 ± 19.4
Extensor muscles (60 and 180°/sec)	23.5 ± 22.0 and 16.2 ± 18.3
Mean strength change after ACL reconstruction (%)	
Flexor muscles (60 and 180°/sec)	-0.9 ± 26.7 and 3.2 ± 27.2
Extensor muscles (60 and 180°/sec)	-16.5 ± 18.7 and - 15.8 ± 22.9

Effect of TFI on strength deficit

The flexor muscle strength deficit before ACL reconstruction in the chronic period was higher than in the acute and subchronic periods at 60°/sec (p = 0.015). Figure 3 shows that in the chronic period the extensor muscle strength deficit was significantly higher than in the acute period at 180°/sec (p = 0.003), and especially at 60°/sec ($p = 0.001$) (*Kruskall-Wallis test)*.

Effect of TFI on strength change

When the flexor muscle strength change was evaluated according to the TFI, especially when acute and chronic cases were compared, the flexor

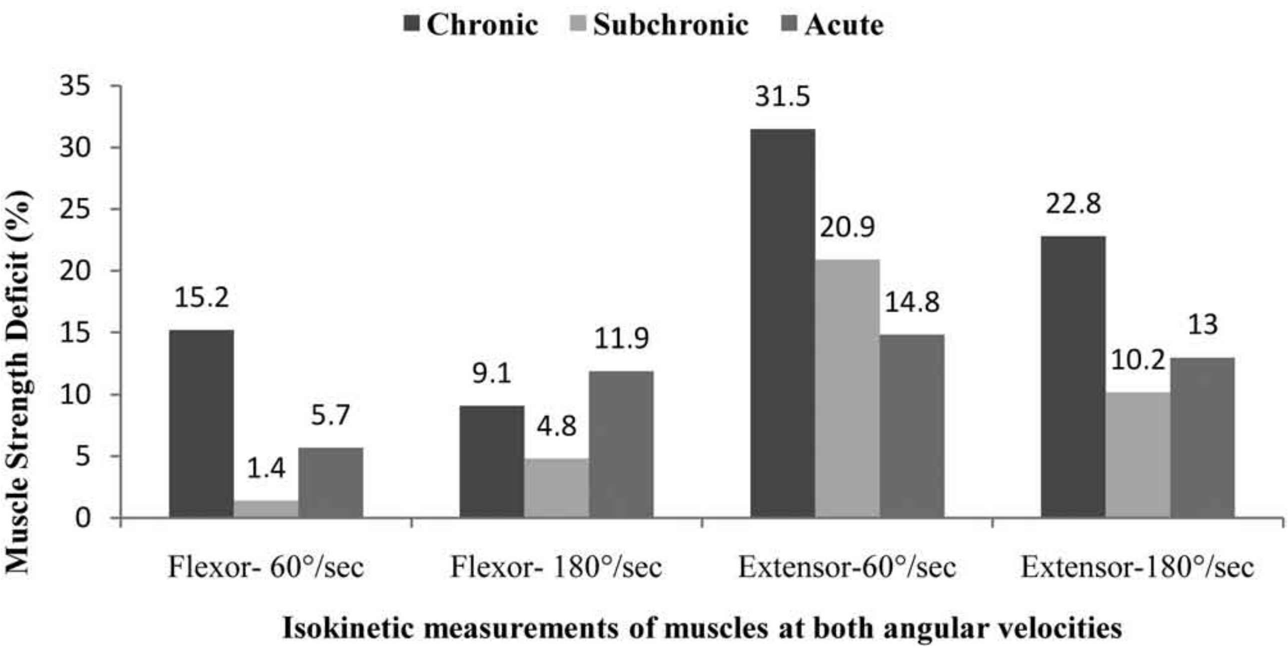

Fig. 3. — Mean muscle strength deficit values of the flexor and extensor muscles in the ACL-deficient knee when patients were grouped according to the time from injury (Flexor : flexor muscle ; Extensor : extensor muscle).

muscle strength change values were affected negatively at 60°/sec ($p = 0.0001$) and 180°/sec ($p = 0.0001$). However, the alteration in the TFI did not significantly affect the extensor muscle strength change at 60°/sec ($p = 0.519$) or 180°/sec ($p = 0.182$) (Fig. 4) *(Kruskall-Wallis test)*.

The effect of MS deficit on MS change

In Group I knee flexors at 60°/sec where maximal preoperative strength deficit was seen, strength improved more after ACL reconstruction when compared to Groups II and III ($p = 0.0001$). Similarly, at 180°/sec for flexors, Group I showed more postoperative improvement (+32.7 ± 23.2%) in terms of muscle strength change than Group III, in which the strength deficit before ACL reconstruction was minimal ($p = 0.0001$) *(Kruskal-Wallis test)*. In Group II the gain was + 12.6 ± 14.4 and in Group III flexor muscle strength decreased to -12.7 ± 21.7% (lower than preoperatively).

The extensor muscle strength change after ACL reconstruction at 60°/sec angular velocity in Groups I, II, and III was -10.3 ± 15.8%, -15.6 ± 21.6%, and -30.6 ± 12.7%, respectively. Thus, in Group III (in which the preoperative strength deficit was minimal) the extensor muscle strength of the involved knee at 60°/sec angular velocity revealed a prominent decrease when compared with Groups I and II ($p = 0.0001$). In Group I at 180°/sec the extensor muscle strength change was +3.3 ± 27.1%. In this group, in which the extensor muscle strength deficit was maximal, improvement in terms of extensor muscle strength was better than in Groups II and III, in which the strength deficit was less ($p = 0.001$) *(Kruskal Wallis test)*.

MS change when TFI and MS deficit are considered together

The results of the combined effect of muscle strength deficit and TFI groups on muscle strength change are presented in table II. When the extensor muscle strength change of patients (especially in the acute group) was evaluated, the improvement was higher, when compared with the subchronic

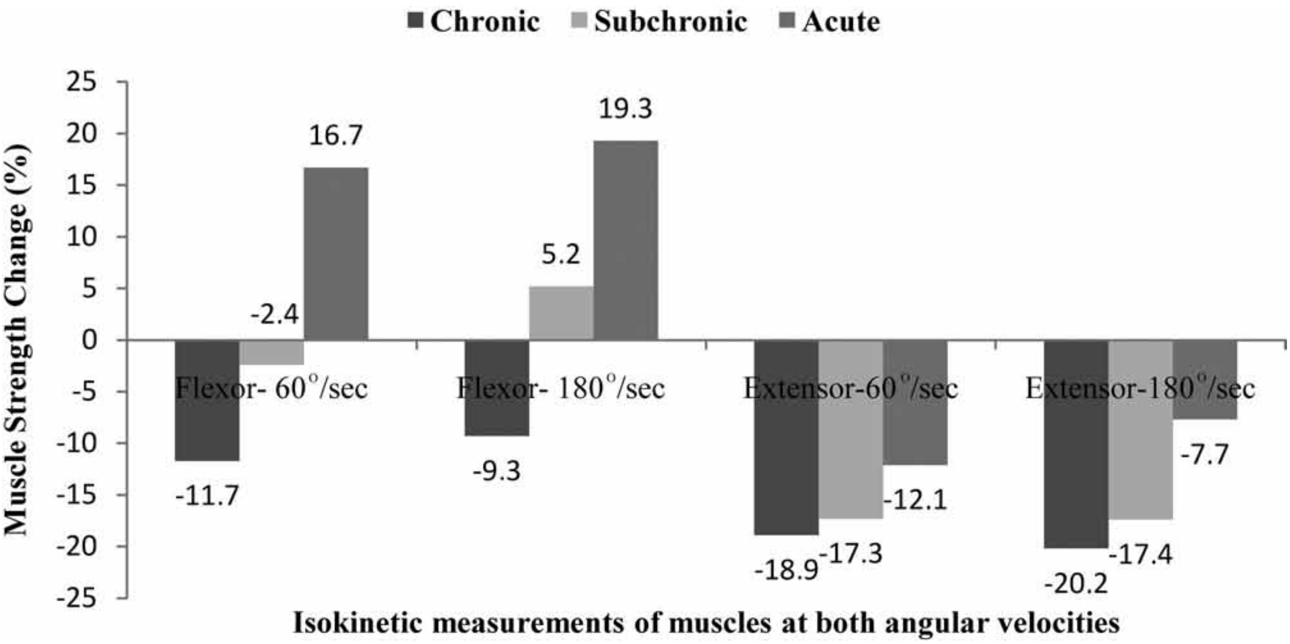

Fig. 4. — Mean strength change values of the flexor and extensor muscles in the ACL-reconstructed knee when patients were grouped according to the time from injury (Flexor : flexor muscle ; Extensor : extensor muscle).

and chronic group ($p < 0.05$). When strength deficit of flexor muscles at both angular velocities was evaluated, the flexor muscle strength change especially in Group III and patients in the acute period improved ($p = 0.0001$) *(Kruskal-Wallis test)*.

The effect of patient compliance to treatment on MS change

Patient compliance to treatment affected flexor muscle strength change at 60°/sec in the involved knee ($p = 0.055$). At 180°/sec, a similar improvement was observed in Group A ($p = 0.017$). However, the extensor muscle strength change of the involved knee at both 60°/sec and 180°/sec was not statistically different between Groups A and B (Table III) *(Mann-Whitney U test)*.

DISCUSSION

Isokinetic muscle strength measurements are generally used in the assessment of graft type or rehabilitation program for ACL-deficient knees (*2,4-9,12,16,18,20,22,27*). Comparison of the results may suggest the superiority of a selected treatment option with regard to muscle strength recovery. In our study, the factors thought to have an influence on muscle strength measurements before and after ACL reconstruction were evaluated in patients with similar graft type, surgical technique and rehabilitation program.

In the present study as in most studies (*4,7,11,12,15-17,22,23,25,26,29*) the extensor muscle strength of the involved knee is weaker than in the uninvolved knee before ACL reconstruction. Some studies do not report a deficit in strength of flexor muscles before ACL reconstruction (*15-17,22,29*), or find a variable muscle strength deficit (*7,11,25,26*). In our study, the mean value of flexor muscle strength deficit before ACL reconstruction at both angular velocities for all patients was 8%, when the involved knee was compared with the uninvolved knee. Maybe the cause of the flexor muscles strength deficit found in our study was the type of dynamometer used or the chosen angular velocity or the prolonged time since injury. Our study revealed that the flexor muscle strength deficit before ACL reconstruction was higher for patients

Table II. — Strength changes of flexor and extensor muscles at both angular velocities when strength deficit before ACL reconstruction and time from injury to arthroscopy groups are considered together. (F : flexor muscle ; E : extensor muscle ; 60 : 60°/sec ; 180 : 180°/sec ; MSD : muscle strength deficit before ACL reconstruction ; MSC : muscle strength change after ACL reconstruction) (* p value < 0.05 statistically significant)

	MSD groups	Acute			Subchronic			Chronic			p value
		# of patients	MSC mean ± SD		# of patients	MSC mean ± SD		# of patients	MSC mean ± SD		
F 60	I	4	38.9	42.8	8	20.4	14.6	16	7.8	21.1	.235
	II	10	19.9	21.9	3	-43.2	.00	12	-16.9	28.2	.007*
	III	20	10.7	24.2	27	-6.3	9.5	22	-23.1	19.7	.0001*
F 180	I	10	44.5	18.5	5	39.1	3.9	10	18.3	24.9	.048*
	II	6	19.9	22.1	15	14.4	8.1	12	6.9	14.6	.107
	III	18	5.1	13.2	18	-9.5	14.9	28	-26.1	21.2	.0001*
E 60	I	8	0.8	9.9	18	-5.9	17.9	34	-14.9	14.3	.022*
	II	12	-2.6	24.8	12	-17.8	13.2	10	-28.4	18.1	.033*
	III	14	-27.5	10.8	8	-39.2	4.7	6	-26.5	19.1	.078
E 180	I	6	34.4	26.6	11	6.2	4.2	22	-9.3	17.7	.0001*
	II	12	-8.5	9.8	7	-29.0	23.8	18	-27.8	11.0	.001*
	III	16	-26.7	9.8	20	-25.8	11.1	10	-30.5	13.1	.731

Table III. — The relationship between the improvement in muscle strength of the uninvolved knee after rehabilitation and the muscle strength change (MSC) in the involved knee. (F : flexor muscle ; E : extensor muscle ; 60 : 60°/sec ; 180 : 180°/sec ; MSD : muscle strength deficit before ACL reconstruction ; MSC : muscle strength change after ACL reconstruction) (* p value < 0.05 statistically significant)

MSC in the injured knee	Groups according to the uninjured knee	# of patients	MSC (%) Mean ±	SD	P value
MSC F 60	A	84	2.2	24.5	.055
	B	38	-8.0	30.4	
MSC F 180	A	84	7.0	24.7	.017*
	B	38	-5.9	30.8	
MSC E 60	A	84	-15.2	18.8	.241
	B	38	-19.6	18.5	
MSC E 180	A	84	-13.9	25.2	.148
	B	38	-20.5	15.7	

in the chronic period, but only at high resistance (low velocity). The extensor muscle strength deficit was also highest in the chronic group, at both angular velocities. The effect of delay to surgery on muscle strength deficit was prominent for extensor muscles tested at low angular velocity, representing high resistance. This relationship between time from injury and muscle strength deficit appears to be logical. Only one study by de Jong *et al* (*7*) has looked at this subject. They found a preoperative quadriceps strength deficit and a decreased limb symmetry index in patients with an ACL deficiency. This strength deficit increased postoperatively, with the highest measured deficit occurring at 6 months postoperatively and a clear improvement from 6 to 12 months. Functional assessment showed identical development. There was a statistically significant relation between an increased quadriceps strength deficit preoperatively and poor early postoperative functional performance.

The effect of time from injury to reconstruction on postoperative isokinetic muscle strength differs for flexor and extensor muscles. Delay in the time from injury to reconstruction affected strength change after ACL reconstruction only for flexor muscles. In our study, the postoperative extensor muscle strength of the involved knee showed a 16% loss. In accordance with previous studies in the literature (*7,12,15-17,29*), our study revealed that strength loss of the ACL-deficient knee continued to increase in the postoperative period. Nevertheless, delay of surgery did worsen the strength deficit of the extensor muscles. A long delay caused a postoperative increase of the preexisting deficit of flexor muscle strength. Patients treated in the acute period had a postoperative flexor muscle strength improvement when compared with preoperative values. This finding in our study suggests that in patients with ACL deficiency, performing an early surgical reconstruction can improve especially flexor muscle strength. In the literature, the only other study suggesting that a shorter time from injury had a positive effect on postoperative muscle strength measurements was performed by Natri *et al* (*21*). Many other studies evaluating the influence of time from injury on postoperative muscle strength measurements could not reveal any significant relationship (*7,10,14,29*). The reasons for our results being different could be due to different times from injury, different timing of postoperative measurement and angular velocity preferences.

Shelbourne *et al* (*23*) reported that in ACL-deficient knees with a higher preoperative deficit in the strength of the quadriceps muscle the postoperative muscle strength of the quadriceps remained low in all follow-up examinations, when compared with patients whose preoperative deficit in extensor muscle strength was lower. In our study, the influence of the deficit in the muscle strength before ACL reconstruction on the change in the muscle strength after ACL reconstruction was evaluated differently. The present study evaluated how the deficit in preoperative muscle strength of the ACL-deficient knee can lead to an alteration in the postoperative muscle strength.

We found that knees with a considerable preoperative loss of muscle strength attained the greatest improvement after ACL reconstruction. This evaluation has a clinical implication in the treatment of patients with ACL deficiency. When preoperative muscle strength deficit is high, postoperative gain is close to the gain of the uninvolved knee and the chances of a successful rehabilitation program are high. This also applies to short delays. Indeed, in patients whose preoperative muscle strength deficit was greater, the shorter the delay the better was the gain in muscle strength. This is true for both flexor and extensor muscle evaluations.

Other than the time from injury and the muscle strength deficit before ACL reconstruction, patient compliance to the treatment was the third factor to have a positive influence on postoperative muscle strength after ACL reconstruction for both flexors and extensors and at both angular velocities. However, this positive effect on strength gained was only statistically significant for the flexor muscle strength and only at high angular velocity.

One limitation of the present study is that the muscle strength measurements were not repeated after the patients returned to their occupational responsibilities and the involved physical and training activities. The other limitation of our study is that our results apply only to ACL-deficient male patients. Similar studies should also be performed on female patients.

In conclusion, isokinetic muscle strength measurements were influenced by the time from injury to reconstruction and factors related to the patients with ACL deficient knee. Prolonged time from injury increased the deficit in muscle strength before ACL reconstruction of flexor and extensor muscles. The only factor affecting both flexor and extensor muscle strength changes after ACL reconstruction by itself was the muscle strength deficit before ACL reconstruction. A shorter delay of surgery and a better patient compliance to treatment, can result in a much better gain of flexor muscle strength after ACL reconstruction. A shorter delay of surgery did only significantly improve postoperative gain of extensor muscle strength when preoperative muscle strength loss was high.

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