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Factors affecting quadriceps strength recovery after anterior cruciate ligament reconstruction with hamstring autografts in athletes

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Abstract

Purpose Patients typically return to sports activities 6–12 months after anterior cruciate ligament (ACL) reconstruction, and quadriceps strength has been used as one of the criteria to return to sports activities. The purpose of this study is to identify the factors that affect quadriceps strength recovery after ACL reconstruction with a hamstring tendon autograft 6 months after surgery.

Methods Isokinetic quadriceps strength at 60°/s was measured preoperatively and 6 months after surgery in 193 athletes who underwent ACL reconstruction with a hamstring tendon autograft. The quadriceps strength index was calculated by normalizing the peak torque of the involved leg with the uninvolved leg. The subjects were divided into two groups according to the quadriceps strength index 6 months after surgery: at least 85 % ($n = 84$) or less than 85 % ($n = 109$). Multivariate logistic regression analysis and a receiver operating curve analysis were performed.

Results The preoperative quadriceps strength index [odds ratio (OR) 1.02; 95 % confidence interval (CI) 1.01–1.03], age (OR 0.92; 95 % CI 0.86–0.98), sex (OR 2.45; 95 % CI 1.19–5.18), and knee pain (OR 0.17; 95 % CI 0.04–0.52) were independently associated with quadriceps strength recovery. The cut-off value of the preoperative quadriceps strength index was 70.2 % to obtain at least 85 % quadriceps strength index 6 months after surgery.

Conclusion To achieve sufficient quadriceps strength recovery at the timing of return to sports activities following ACL reconstruction using a hamstring tendon autograft, preoperative quadriceps strength, age, sex, and knee pain should be considered.

Level of evidence III.

Keywords Anterior cruciate ligament reconstruction · Hamstring tendon autograft · Quadriceps strength recovery · Cut-off value

Abbreviations

ACL	Anterior cruciate ligament
ROC	Receiver operating curve
OR	Odds ratio
CI	Confidence interval
BPTB	Bone–patellar-tendon–bone
SB	Single-bundle
DB	Double-bundle
AMB	Anteromedial bundle
PMB	Posterolateral bundle
GR group	Good quadriceps strength recovery group
PR group	Poor quadriceps strength recovery group
AUC	Area under the curve

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Introduction

Anterior cruciate ligament (ACL) injury is one of the most common knee injuries, and it often occurs during sports activities [13]. To treat patients with ACL ruptures, surgery is often required, and ACL reconstruction has become the most common surgical procedure [26, 27]. Most of the previously published studies have reported good clinical outcomes after ACL reconstructions with regard to knee stability [24, 26], and subjective assessments [11, 20]. Although relatively good clinical outcomes have been reported, weak quadriceps strength after ACL reconstruction has also been reported [4, 8, 9].

It has been reported that quadriceps strength is associated with knee function and patient satisfaction after ACL reconstruction [12, 16, 23, 28]. In addition, quadriceps strength has been used as one of the criteria to determine when patients can return to sports activities. Previous studies have suggested that achieving at least 85 % quadriceps strength compared with the uninvolved leg is a criterion to allow patients to return to sports activities after ACL reconstruction [14, 17, 22]. Although there is no consensus regarding the appropriate timing of return to sports after ACL reconstruction, patients typically return to sports 6–12 months after the surgery [2, 3, 18] or start sports-specific training 6 months after surgery. Therefore, obtaining sufficient muscle strength 6 months after the surgery is an important step towards safe return to sports.

Some of the factors affecting post-operative quadriceps strength recovery after ACL reconstruction using a bone–patellar-tendon–bone (BPTB) autograft have been reported, and they include preoperative quadriceps strength and patellar tendon width [5, 19]. Even though the quadriceps are not primarily affected during ACL reconstructions using a hamstring graft, deficits in quadriceps strength are often seen after surgery [8, 9]. Although some previous studies reported factors associated with quadriceps strength after ACL reconstruction using hamstring tendon graft [6, 7], the confounding factors were not adjusted adequately. In addition, the factors that affect post-operative quadriceps strength after ACL reconstruction with a hamstring tendon autograft have not yet been extensively examined, with a focus on the timing of return to sports.

Therefore, the purpose of this study was to identify the factors affecting post-operative quadriceps strength recovery 6 months after ACL reconstruction with a hamstring tendon autograft in athletes. The present study will provide a clinically important information for constructing a better rehabilitation programme for patients with an ACL injury.

Materials and methods

The study included patients who underwent ACL reconstruction from 2007 to 2014. All of the patients had quadriceps strength measurements taken preoperatively and again approximately 6 months after the ACL reconstruction. To define athletes for this study, the pre-injury Tegner activity scale [21] of at least 7 was used to define athletes for this study. The study inclusion criteria were patients with (1) ACL reconstruction with a hamstring graft, (2) pre-injury Tegner activity scale of at least 7, (3) patients who participated regularly in rehabilitation at an outpatient clinic for at least 6 months after the surgery. The exclusion criteria were: patients with (1) bilateral knee injury, (2) a history of ACL reconstruction on the ipsilateral side, (3) a multiligament reconstruction, and (4) an ACL reconstruction with a BPTB graft. A total of 193 athletes were included in this study.

Surgical technique

The surgical techniques performed in this study included single-bundle (SB) and double-bundle (DB) ACL reconstructions. A total of 61 patients underwent SB ACL reconstruction, and 132 patients underwent DB ACL reconstruction. During the single-bundle reconstruction, single femoral and single tibial tunnels were created at a central position between the original insertion of the anteromedial bundle (AMB) and the posterolateral bundle (PMB). During the double-bundle reconstruction, two femoral and two tibial tunnels were created to reconstruct the AMB and the PMB, as previously described [10]. Either the semitendinosus tendon alone or both the semitendinosus and gracilis tendons were harvested for the graft.

Rehabilitation protocol

All patients were treated with almost identical rehabilitation protocols for the first 6 months after the surgery. Progressive range of motion exercises and partial weight bearing with crutches were started as tolerated the day after surgery. Full knee extension and full weight bearing were allowed with a knee brace, starting 2 weeks after the surgery. If concomitant meniscal repair was performed for an incomplete or complete tear, the weight bearing was delayed for 1 week and the range of motion exercises were delayed for 2 weeks. The rehabilitation protocol was intended to improve range of motion, lower muscle strength, and proprioceptive sensation, and it was performed at an outpatient rehabilitation centre at a hospital or clinic. Jogging was permitted approximately 3 months after the surgery. The rehabilitation protocol consisted of time-based menus depending on the time after surgery.

Measurements

The patient demographic data including age, sex, height, weight, pre-injury Tegner activity scale, time from injury

to surgery, surgical technique (SB or DB), cartilage injury, meniscus injury (requiring surgical treatments), and the number of times the patient participated in post-operative rehabilitation at an outpatient were obtained from patient interviews and medical records. Anterior knee laxity was measured using the KT-1000 knee arthrometer (MEDmetric Corp., San Diego, CA, USA) with manual maximum force. The side-to-side difference in the anteroposterior tibial displacement between the repaired knee and the contralateral healthy knee was calculated and expressed in millimetres.

The maximum isokinetic strength of the quadriceps was assessed using the MYORET, RZ-450 (Kawasaki Heavy Industries, Ltd. Kobe, Hyogo, Japan). Prior to the muscle strength test, the subjects warmed up using a stationary cycling ergometer at a low resistance for 5 min. The test was performed with the uninvolved leg first. Each subject performed two practice contractions followed by five maximal effort contractions at 60°/s, and the peak extension torque was recorded. The test was then repeated on the involved leg. During the quadriceps strength measurement, we queried the subjects about whether they were feeling knee pain. The quadriceps strength index was calculated by normalizing the peak torque of the involved leg with the uninvolved leg and multiplying it by 100. As a preliminary study, quadriceps strength of the uninvolved leg was evaluated two times with one-week interval before surgery in six patients and the coefficient of correlation of the first and the second measurement was calculated. The preliminary study showed a high positive correlation ($r = 0.94$) between the first and the second measurement values.

Institutional review board approval was obtained from the ethics committee in Kobe University Graduate School of Medicine (Approval No. 1377).

Statistical analysis

The subjects were divided into two groups according to post-operative quadriceps strength index determined 6 months after surgery, and they were referred to as the good quadriceps strength recovery (GR) group and the poor quadriceps strength recovery (PR) group. The GR group included the subjects who had at least 85 % quadriceps strength index, and the PR group included the subjects who had less than 85 % quadriceps strength index.

A univariate analysis was performed to determine the differences between the two groups. Differences in nominal variables were tested with the Chi-squared test. Differences in continuous variables with a normal distribution were tested with the unpaired t test, and differences without a normal distribution were tested with the Mann–Whitney U test. A multivariate logistic regression analysis was conducted to determine the factors that affected the post-operative quadriceps strength index at 6 months. The post-operative quadriceps strength index at 6 months was selected as the dependent variable. The outcomes with a P value of 0.10 or lower between the two groups were selected as independent variables. The cut-off value of the preoperative quadriceps strength index for good quadriceps strength recovery after an ACL reconstruction using a hamstring tendon autograft was determined. The receiver operating characteristic (ROC) curves and the area under the curve (AUC) were assessed as previously described [1, 25]. The sample size for this study was estimated as following. The standard deviation of preoperative quadriceps strength was set as approximately 20 % in a preliminary study. Considering that 10 % is clinically an important difference for preoperative quadriceps strength, the minimal sample size to achieve an alpha of 0.05 and a beta of 0.80 was 128.

Results

The mean post-operative quadriceps strength index for all the patients was 81.1 ± 19.2 %. Of the 193 subjects, 84 patients (43.5 %) were included in the GR group and 109 patients (56.5 %) were included in the PR group.

The mean age at the time of surgery in the GR group was significantly younger than in the PR group. The ratio of male patients was significantly higher in the GR group than in the PR group. There were no statistically significant differences in the other demographic data between the two groups (Table 1).

The mean preoperative quadriceps strength index was significantly higher in the GR group than in the PR group. The number of patients who had knee pain during the quadriceps strength test 6 months after the surgery was significantly higher in the PR group than in the GR group. No significant differences in knee laxity were observed between the two groups, either preoperatively or 6 months after surgery (Table 1).

Based on the results of the univariate analysis, age, sex, pre-injury Tegner activity scale, preoperative quadriceps strength index, and knee pain 6 months after the surgery were selected as independent variables. The multivariate logistic regression analysis showed that the preoperative quadriceps strength index was independently associated with the post-operative quadriceps strength [odds ratio (OR), 1.02; 95 % confidence interval (95 % CI) 1.01–1.03; $P = 0.015$]. Age (OR 0.92; 95 % CI 0.86–0.98; $P = 0.006$), sex (OR 2.45; 95 % CI 1.19–5.18; $P = 0.015$), and knee pain (OR 0.17; 95 % CI 0.04–0.52; $P = 0.001$) were also independently associated with post-operative quadriceps strength recovery (Table 2). The preoperative quadriceps strength index and sex were also independently associated with the post-operative quadriceps strength at 1 year after surgery (Supplemental Tables 1 and 2).

Table 1 Comparison between good quadriceps strength recovery group and poor quadriceps strength recovery group

	All $N = 193$	GR group $n = 84$	PR group $n = 109$	*P* value
Demographic data				
Age at the time of surgery (year)	21.0 ± 6.8	19.7 ± 5.9	22.0 ± 7.3	0.04*
Sex (male)	106 (54.9)	54 (64.3)	52 (47.4)	0.02*
Height (cm)	166.7 ± 9.1	167.6 ± 9.1	166.0 ± 9.1	n.s.
Weight (kg)	62.7 ± 12.6	63.8 ± 12.4	61.9 ± 12.8	n.s.
Pre-injury Tegner activity scale	8.0 ± 1.0	8.1 ± 1.0	7.9 ± 1.0	0.09†
Time from injury to surgery (month)	6.8 ± 14.2	6.4 ± 11.6	7.1 ± 16.0	n.s.
Surgical technique (DB)	132 (68.4)	55 (65.5)	77 (70.6)	n.s.
Cartilage injury (yes)	15 (8.8)	5 (6.0)	10 (9.2)	n.s.
Meniscus injury (yes)	85 (44.0)	33 (39.3)	52 (47.7)	n.s.
Number of patients participated in outpatient rehabilitation after surgery more than 2 times per week				
From 1 day to 3 months after surgery (yes)	120 (62.2)	53 (63.1)	67 (61.5)	n.s.
From 3 to 6 months after surgery (yes)	75 (38.9)	33 (39.3)	42 (38.5)	n.s.
Preoperative				
Quadriceps strength index (%)	67.9 ± 22.7	74.1 ± 22.1	63.1 ± 22.1	<.001*
Knee pain during quadriceps strength measurement (yes)	38 (19.7)	14 (16.7)	24 (22.0)	n.s.
Knee laxity (mm)	5.5 ± 2.8	5.5 ± 2.9	5.5 ± 2.7	n.s.
Post-operative				
Quadriceps strength index (%)	81.1 ± 19.2	97.1 ± 11.3	68.8 ± 14.3	<.0001*
Knee pain during quadriceps strength measurement (yes)	30 (15.5)	3 (3.6)	27 (24.8)	<.0001*
Knee laxity (mm)	1.5 ± 2.5	1.4 ± 2.2	1.5 ± 2.7	n.s.

Values are shown as mean ± standard deviation for continuous variables, *n* (%) for nominal variables. *GR group* Good quadriceps strength recovery group, *PR group* Poor quadriceps strength recovery group, *DB* Double-bundle, *n.s.* not significant

* *P* value < 0.05

† *P* value < 0.10

Table 2 Result of the multivariate logistic regression analysis

	OR	95 % CI	*P* value
Preoperative quadriceps strength index (%)	1.02	1.01–1.03	0.015*
Age at the time of surgery (year)	0.92	0.86–0.98	0.006*
Sex (male)	2.45	1.19–5.18	0.015*
Pre-injury Tegner activity scale	1.03	0.73–1.44	n.s.
Knee pain during quadriceps strength measurement 6 months after the surgery (yes)	0.17	0.04–0.52	0.001*

Dependent variable: quadriceps strength recovery. *OR* odds ratio, *95 %CI* 95 % Confidence Interval, *n.s.* not significant

* *P* value < 0.05

The ROC analysis revealed that the cut-off value of the preoperative quadriceps strength index for obtaining 85 % quadriceps strength index at 6 months was 70.2 % (AUC = 0.65; sensitivity = 69.1 %; specificity = 61.5 %) (Fig. 1).

Discussion

The most important finding of the present study was that factors affecting quadriceps strength recovery after ACL reconstruction using a hamstring autograft in athletes were identified. The most important finding of the present study was that the preoperative quadriceps strength index was independently associated with post-operative quadriceps strength following an ACL reconstruction using a hamstring tendon.

Some studies have reported the association between pre- and post-operative quadriceps strength after ACL reconstructions performed with a BPTB graft [4, 5, 19]. Eitzen et al. [5] found that patients with preoperative quadriceps

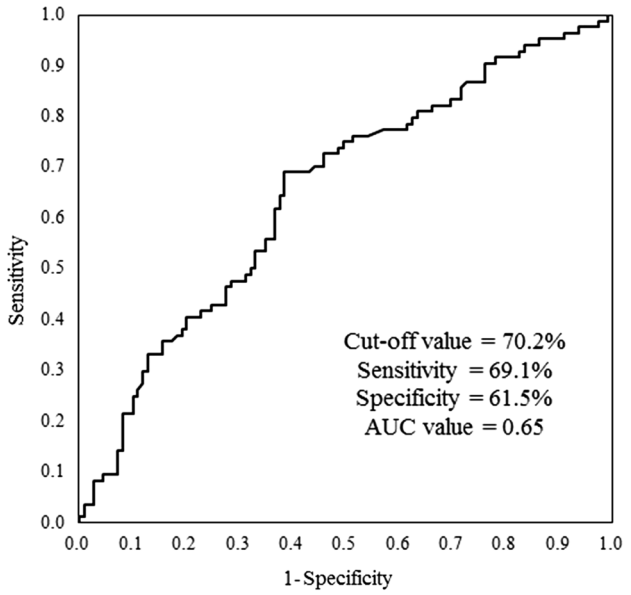

Fig. 1 Receiver operating characteristics (ROC) *curve* was constructed to determine the best cut-off value of preoperative quadriceps strength index to achieve good quadriceps strength recovery 6 months after anterior cruciate ligament (ACL) reconstruction using a hamstring tendon autograft. The cut-off value is 70.2 %. The sensitivity and specificity of the preoperative quadriceps strength index at 70.2 % are 69.1 and 61.5 %, respectively. The area under the curve (AUC) is 0.65

strength deficits greater than 20 % had significantly lower quadriceps strength 2 years after ACL reconstruction with BPTB graft. Shelbourne and Johnson [19] also reported that patients with more than 90 % preoperative quadriceps strength compared with the uninvolved leg had significantly higher quadriceps strength at 1, 2, 3, 12, and 24 months after undergoing an ACL reconstruction with a BPTB graft. Similar to those previous studies, the present study determined that preoperative quadriceps strength was associated with post-operative quadriceps strength at 6 months and 1 year, suggesting that preoperative quadriceps strength is an important factor affecting post-operative quadriceps strength after ACL reconstruction using a hamstring tendon autograft. The cut-off value of the preoperative quadriceps strength index determined in the current study was 70.2 %. Therefore, if the preoperative quadriceps strength index is not greater than 70 %, it might be advisable to perform preoperative rehabilitation in order to obtain at least 85 % quadriceps strength index 6 months after surgery.

In the present study, age and sex were associated with lower quadriceps strength 6 months after ACL reconstruction. Using a multiple logistic regression analysis, Iriuchishima et al. [7] reported that age was the only factor associated with residual muscle weakness 9 months after ACL reconstruction using a hamstring autograft. In contrast, Gobbi et al. [6] reported that female patients had a higher deficit in the peak torque of knee extension and flexion than male patients 1 year after ACL reconstruction with a hamstring graft. When considered together with our finding, these reports suggest that age and female gender could be predictors for delayed quadriceps recovery after ACL reconstruction. Therefore, gender-specific and age-specific rehabilitation programmes may need to be considered to facilitate better muscle recovery after ACL reconstruction.

Knee pain during the post-operative quadriceps strength examination was also associated with lower quadriceps strength in our study. Similar to our findings, other studies have suggested that anterior knee pain may delay recovery in muscle strength after ACL reconstruction [6, 15]. Knee pain can be caused by cartilage and meniscal injuries. However, in the present study, there was no statistically significant difference in the ratio of associated cartilage and meniscal injuries. Currently, we do not know the exact cause of knee pain after ACL reconstruction; future studies are needed to elucidate the mechanism of knee pain after ACL reconstruction using a hamstring tendon autograft.

There were some limitations to this study. First, the subjects were restricted to patients who had a pre-injury Tegner activity scale of at least seven. Thus, the results might be different in patients with a pre-injury Tegner activity scale of less than seven. Second, although the same post-operative rehabilitation protocol was used, home exercise was not assessed in this study. The unquantified home exercise might be one of the reasons why the number of out-patient post-operative rehabilitation sessions completed by the patients did not significantly affect post-operative quadriceps strength recovery. Third, the sensitivity and the specificity of the preoperative quadriceps strength index on the ROC analysis were not high. The reasons for this discrepancy may be that post-operative quadriceps strength was influenced by multiple factors, such as age, sex, knee pain, and rehabilitation after the surgery. Fourth, we did not have an information about test–retest reliability of the whole measurement.

Despite all the limitations, the present study provided a useful information for constructing a better rehabilitation programme for patients who receive ACL reconstruction using a hamstring tendon autograft.

Conclusion

Age, sex, knee pain, and preoperative quadriceps strength were the factors associated with quadriceps strength recovery 6 months after ACL reconstruction using a hamstring tendon autograft in athletes. The cut-off value of the preoperative quadriceps strength index for obtaining 85 %

of quadriceps strength of the uninvolved side at 6 months was 70.2 %. Surgeons should consider about the factors to achieve sufficient quadriceps strength recovery at the timing of return to sports activities after ACL reconstruction using a hamstring tendon autograft.

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Authors' contribution Y. U was involved in the conception and design of the study, the acquisition, analysis and interpretation of the data, and writing the article. T. Matsushita was involved in the conception and design of the study, development of the research, and writing the article. D. A, Y. Shibata, and R. O were involved in the conception and design of the study. A. K, K. Takiguchi, Y. Shibata, and K. O were involved in the acquisition of the data. All of the authors were involved in the critical revisions of the article for its important intellectual content, and they all approved the final version of the article.

Compliance with ethical standards

Conflict of interest The all authors declare that they have no conflict of interest associated with this study.

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Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required

Informed consent Informed consent was obtained from all individual participants included in the study.

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