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Factors affecting the post-operative over-constraint after anatomic double-bundle anterior cruciate ligament reconstruction☆

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ABSTRACT

Objective: Initial tension at graft fixation is one of key factors for good outcomes in anterior cruciate ligament (ACL) reconstruction. Identifying the pre-operative factors that influence postoperative knee laxity under the anterior tibial load is useful in determining the initial tension at graft fixation. Thus, the purpose of this study was to clarify the pre-operative factors affecting the side-to-side difference in anterior laxity immediately after the anatomic double-bundle ACL reconstruction with a constant initial tension.

Methods: Fifty-five patients underwent the anatomic double-bundle ACL reconstruction with hamstring tendon grafts. Anterior tibial displacement (ATD) was measured on both knees using KT-2000 Knee Arthrometer under anterior drawer load of 67 N, 89 N, 134 N and manual maximum load at 30° of flexion before ACL reconstruction under anesthesia, and was also measured on the operated knees under 89 N immediately after ACL reconstruction under anesthesia. Then, side-to-side difference (SSD) before and immediately after ACL reconstruction was calculated. Correlative relation between the SSD immediately after ACL reconstruction and the ATD/the SSD in each condition was analyzed.

Results: The side-to-side difference of ATD immediately after surgery was -3.8 ± 1.7 mm (0 to -8mm) in response of 89 N of anterior load. There was correlation between the SSD immediately after ACL reconstruction and all ATD on both knees except for the ATD under manual maximum load on the injured knee, while little correlation between the SSD immediately after ACL reconstruction and that before ACL reconstruction was found. Especially, ATD under 89 N on the opposite knees and ATD under 134 N on the injured knees showed selective correlation with the SSD immediately after surgery in the step-wise multiple regression analysis.

Conclusion: As the anterior tibial displacements under 89 N on the contra-lateral knee and under 134 N on the injured knee had a significant correlation with the SSD immediately after ACL reconstruction, those values may be helpful in determining the increase or decrease in initial tension at graft fixation.

1. Introduction

Several factors such as tunnel location, tunnel number, graft selection and rehabilitation program must be essential to achieve successful reconstruction. Among them, initial tension at graft fixation is one of key factors for good outcomes in anterior cruciate ligament (ACL) reconstruction. Though there were some clinical studies to clarify the effect of initial tension on the outcomes after ACL reconstruction,[1–4] the optimal initial tension at the time of graft fixation still had room for discussion. Yoshiya et al.[5] compared microangiographically and histologically ACL grafts 3 months after ACL reconstruction in dogs between different two initial tensions, and reported that the grafts under the higher tension underwent focal degeneration and that the collagen fibers within them were replaced by mucoid extra-cellular matrix. Excessive high tension can also make the joint stiffer, bring abnormal knee kinematics, hinder flexion-extension, and lead to graft failure or articular cartilage

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degeneration,[6–12] while insufficient initial tension to the graft may lead to loose knees. Therefore, it can be interesting to determine the optimal initial tension before operation.

Taking load relaxation to the graft following its fixation and its remodeling process into account, the initial tension should be somewhat greater than the laxity match pretension (the tension to restore the normal laxity). The average laxity match pretension in anatomic double bundle ACL reconstruction was previously reported as 7.3 N and 20 N of initial tension was minimally required at graft fixation.[13,14] However, in those with 20 N of initial graft tension in anatomic double-bundle reconstruction, some showed over-constraint immediately after ACL reconstruction.[14] It is conceivable that the optimal initial tension differs for each individual and it would be desirable to know the optimal initial tension for each patient. Then, we focused on pre-operative patients' information and would like to determine the required initial tension at graft fixation based on the pre-operative information. The objective of this study was to find out the pre-operative factors affecting the side-to-side difference in anterior laxity immediately after anatomic double-bundle ACL reconstruction. Our hypothesis was the larger anterior laxity before operation in response to anterior tibial load would lead to larger absolute value in post-operative side-to-side difference.

2. Materials & methods

2.1. Subjects

Fifty-five consecutive patients suffering from unilateral ACL insufficiency had the anatomic double-bundle ACL reconstruction from September 2004 to October 2005. There were 28 males and 27 females, and the mean age was 29.6 years (Table 1). 17 cases had medial meniscal tears and 21 cases had lateral meniscal tear. Of the knees with a medial meniscal tear, 12 underwent meniscectomy, 3 had meniscal repair and 2 underwent just rasping. Of the knees with a lateral meniscal tear, 13 underwent meniscectomy, 4 had meniscal repair, and 4 underwent rasping. Those patients had no obvious instability by the other ligamentous injury as well as no severe cartilage damage. They also had no history of injury on both knees. All patients consented to participate in this study, which has been approved by the institutional research board of our hospital.

Table 1
Patients' demographic data.

Age (y.o.)	29.6 ± 12.7 (14–60)
Gender (male/female)	28/27
Height (cm)	165.1 ± 7.1
Weight (kg)	58.9 ± 6.0
Meniscal tear (medial/lateral)	17/21

2.2. Anatomic double-bundle ACL reconstruction

[15]All ACL reconstructions were performed by two surgeons (T.M, N. M) with more than 15-year experience of arthroscopic surgeries. After removal of ACL remnant tissues around footprint, two femoral tunnels of 5.0–6.0 mm in diameter were created behind the resident's ridge and just anterior to the cartilage margin (Fig. 1a). Two tibial tunnels of 5.0–6.5 mm in diameter were also created in the ACL attachment surrounded by anterior ridge, medial intercondylar ridge, and anterior horn of lateral meniscus (Fig. 1b). Previously harvested semitendinosus tendon was cut in half and was folded to make a pair of doubled grafts. Endobutton-CL® (Smith & Nephew Inc. Endoscopy, Andover, MA, USA) of appropriate length based on the femoral tunnel length was placed to the loop end of the graft, and two No.3 polyester threads were sutured to the free end of each doubled graft with Krackow technique. After grafts were fixed at femoral side with EndoButtons, the graft sutures at tibial side were separately connected to two Double Spike Plates (DSP; Smith & Nephew Inc. Endoscopy, Andover, MA). The grafts were fixed at tibia using a tensioning boot system with total 20 N (10 N to each graft) of initial tension applied to grafts at 20° of knee flexion.[16]

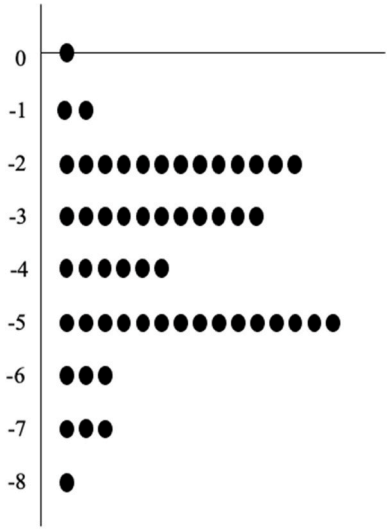

Fig. 2. Distribution of the side-to-side difference immediately after ACL reconstruction under anesthesia ranged from −8 to 0 mm.

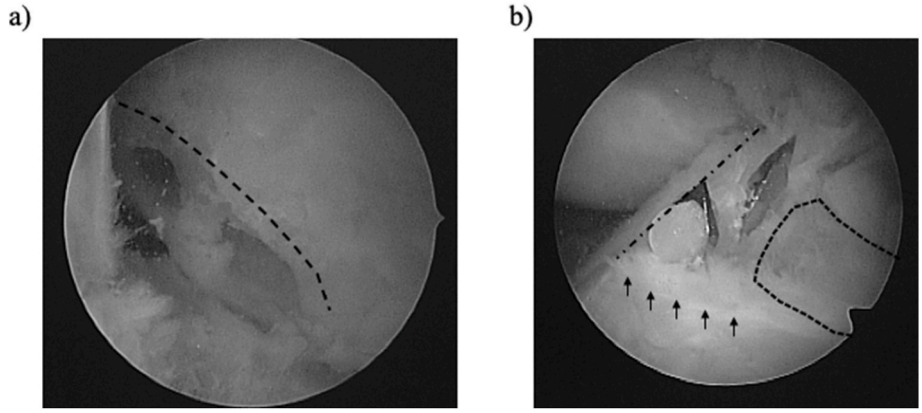

Fig. 1. Tunnel location in anatomic double-bundle ACL reconstruction. a) femoral side. Femoral tunnels were created behind the resident's ridge (dotted line) and just anterior to the cartilage margin. b) tibial side. ACL footprint is surrounded by anterior ridge (arrows), medial intercondylar ridge (wavy line), and anterior horn of lateral meniscus (dotted line).

Table 2
Correlation between pre-operative anterior knee laxity/side-to-side difference (SSD) and the SSD of knee laxity immediately after ACL reconstruction under general anesthesia with KT Knee Arthrometer.

Anterior load	Pre-operative laxity (Injured knee)		Pre-operative laxity (Opposite knee)		Pre-operative SSD	
	Mean ± SD	Correlation coefficient ρ-value (p-value)	Mean ± SD	Correlation coefficient ρ-value (p-value)	Mean ± SD	Correlation coefficient ρ-value (p-value)
67 N	6.4 ± 2.2 mm	−.450* (p = .001)	4.3 ± 1.8 mm	−.714* (p < .001)	2.1 ± 1.8 mm	.199 (p = .145)
89 N	10.7 ± 2.9 mm	−.457* (p < .001) 6.9 ± 1.8 mm	−.863* (p < .001)	3.8 ± 1.8 mm	.009 (p = .947)	
134 N	15.2 ± 3.2 mm	−.285* (p = .035)	9.6 ± 2.3 mm	−.705* (p < .001)	5.6 ± 2.7 mm	.193 (p = .159)
Manual max.	19.5 ± 3.6 mm	−.169 (p = .216)	11.2 ± 2.3 mm	−.583* (p < .001)	8.4 ± 3.3 mm	.180 (p = .188)

2.3. Laxity measurements

Anterior tibial displacement (ATD) on both knees was measured using KT-2000 Knee Arthrometer (MED metric, San Diego, CA) under anterior drawer load of 67 N (15 l b), 89 N (20 l b), 134 N (30 l b) and manual maximum load at 30° of flexion before ACL reconstruction under anesthesia.[17] Anterior displacement on the operated knees was also measured under 89 N immediately after ACL reconstruction under anesthesia in the same manner. Then, the side-to-side difference (SSD; injured knee minus opposite healthy knee) before and immediately after ACL reconstruction was calculated. All measurements were performed by one experienced surgeon (T.M).

2.4. Statistical analysis

The number of cases in this study was fifty-five and could be acceptable, as the result of power analysis was 0.99. Then, correlative relation between the SSD immediately after ACL reconstruction and the anterior displacement/the SSD in each condition was analyzed. Kolmogorov-Smirnov analysis was firstly performed to clarify the normal distribution on the SSD immediately after surgery and could not show the normal distribution ($p = .001$). Then, Spearman's rank correlation coefficient was used to analyze the correlative relation. Less than 0.05 of p-value was considered as significant difference.

Moreover, a step-wise multiple regression analysis (using the step-wise option) was conducted to identify the pre-operative laxity and SSD affecting the post-operative SSD using SPSS software, version 21 for Mac (IBM Corp., Armonk, NY). And multiple regression analysis (the forced entry method) was also performed to clarify the patients' demographic data affecting the excessive post-operative SSD.

3. Results

Anterior tibial displacement on the injured knee, which was 10.7 ± 2.9 mm before ACL reconstruction under 89 N of anterior load, improved to 3.1 ± 1.0 mm immediately after operation, and the side-to-side difference was −3.8 ± 1.7 mm (0 to −8 mm) in response of 89 N of anterior load (Fig. 2, Table 2). There was correlation between the SSD immediately after ACL reconstruction and all ATD on both knees except for the ATD under manual maximum load on the injured knee, while any correlation between the SSD immediately after ACL reconstruction and that before ACL reconstruction was not found (Table 2).

In our step-wise multiple regression analysis with SSD under 89 N immediately after ACL reconstruction as the dependent variable, ATD under 89 N on the opposite knees and ATD under 134 N on the injured knees were selected (Table 3). The other pre-operatively measured factors did not significantly contribute to this model (Table 4).

A significant regression equation on the selected factors was found ($F = 81.488$, $p < .0001$) with an R^2 of 0.758. Moreover, in the multiple regression analysis with the SSD under 89 N immediately after surgery, any factors in individual background did not show the significant contribution (Table 5).

4. Discussion

The principle of this study was that the ATD under any anterior loads on both knees except for the ATD under manual maximum load on the injured knee had a significant correlation with the SSD immediately after ACL reconstruction. Especially, the ATD under 89 N on the opposite knees and the ATD under 134 N on the injured knees could be the indicators to expect the post-operative SSD value.

When the graft is fixed at the same tension in every case, some cases can show excessive small SSD even if the tension is set at the minimally-required tension. In the current study the initial tension at graft fixation was set at 20 N of small tension, whereas seven cases showed less than -5mm of SSD immediately after surgery, which was excessively small. As

Table 3
Coefficient of linear regression analysis with stepwise methods.

Selected factors	Unstandardized Coefficients		Standardized Coefficients	t	*P*-value	95 % Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower bound	Upper bound	Tolerance	VIF
(constant)	804	.600		1.340	.186	−.400	2.008		
Pre-op ATD under 89 N on contra-lateral knee	−.972	.082	−.996	−11.857	.000	−1.137	−.808	.659	1.517
Pre-op ATD under 134 N on injured-knee	141	.046	.25	3.083	.003	.049	.234	.659	1.517

ADT: anterior tibial displacement.

Table 4
P-value of each parameters including selected ones by stepwise analysis.

Anterior load	Pre-operative laxity (Injured knee)	Pre-operative laxity (Opposite knee)	Pre-operative SSD
67 N	.580	.470	.365
89 N	.077	<.001	.077
134 N	.003	.512	.512
Manual max.	.993	.530	.673

Table 5
Coefficient of multiple regression analysis.

Patients' factors	Unstandardized Coefficients		Standardized Coefficients	t	p-value	95 % Confidence Interval for B		Collinearity Statistics	
	B	Std Error	Beta			Lower bound	Upper bound	Tolerance	VIF
(constant)	−14.908	21.836		−0.683	.498	−58.790	28.974		
Age	−0.02416	.020	−.174	−1.211	.232	−0.064	.016	.914	1.094
Gender	.334	1.370	.097	.244	.808	−2.418	3.086	.120	8.307
Height	.07209	152	.293	.475	.637	−0.233	.377	.049	20.205
Weight	−0.01650	.116	−.057	−0.142	.888	−0.250	.217	.117	8.521
Mescus tearni	.760	.492	.218	1.546	.129	−0.228	1.748	.950	1.053

excessive tension in anterior cruciate ligament (ACL) reconstruction led to deteriorative effects on remodeling of grafts or to degeneration of articular cartilage[5,11] the initial tension could be smaller for cases with excessive small SSD, and it is desirable to fix the graft with the tension based on the individual laxity. Considering 3.1 mm of the immediate post-operative average anterior laxity on the injured knee, the smaller initial tension would be preferable in cases with a pre-operative ATD of more than 8 mm under 89 N on the contra-lateral healthy knee to keep the post-operative SSD within 5 mm. The current study also supported this suggestion, as the ATD under 89 N of anterior load on the opposite knee had a strong correlation with the post-operative SSD.

The ATD under 134 N on the injured knees also had a strong correlation with the SSD immediately after surgery under 89 N. In single-factor correlation analysis, the pre-operative ATD under 134 N on the injured knee also showed a significant correlation with the SSD immediately after ACL reconstruction and the ρ-values for pre-operative laxity on the injured knee were negative. This means the SSD immediately after ACL reconstruction becomes small when the pre-operative ATD on the injured knee is large. On the other hand, in the step-wise multiple regression analysis, pre-operative ATD under 134 N on the injured knee showed positive B-value, as the pre-operative ATD under 89 N on the opposite knee could greatly affected this result (B-value is −0.972). Thus, the factor that needs to be considered the most would be pre-operative ATD under 89 N on the opposite knee.

Anterior tibial displacement at manual maximum load is one of the most commonly used factors in evaluation of anterior cruciate ligament injury. However, in the present study, the pre-operative ATD and the SSD at manual maximum load did not correlate with the SSD immediately after ACL reconstruction. The main reason for this can be that the ATD was measured under only 89 N of anterior tibial load immediately after surgery and that the SSD under only 89 N of anterior tibial load immediately after surgery was used as an independent variable. Thus, the results might have been different if the ATD had been measured immediately after ACL reconstruction with manual maximum load and the SSD under manual maximum load immediately after surgery had been used as the independent variable.

There were some limitations in the current study. First, the anterior laxity immediately after ACL reconstruction was measured just in response to 89 N of anterior load. As larger anterior load might decrease the graft tension after graft fixation, 89 N of anterior load was adopted to evaluate the immediate-postoperative anterior laxity. Second, knee laxity just before and just after the surgery was only measured. We need to carefully monitor the effects on the long-term course of clinical outcomes after surgery. Third, this study used one procedure with one tension and semitendinosus tendon to eliminate various factors. The results might be changed in case of the other procedures.[18–20] Forth, the subjects used in this study were quite old. As we started an anatomic double-bundle ACL reconstruction from January 2002, fixed grafts with constant 20 N of initial tension since September 2004 and changed our ACL procedure from double-bundle to triple-bundle technique since November 2005, only these cases could be collected. However, the double-bundle ACL reconstruction is more common than triple-bundle and was performed by surgeons with more than 15-year experience even then.

5. Conclusions

As the anterior tibial displacements under 89 N on the contra-lateral knee and under 134 N on the injured knee had a significant correlation with the SSD immediately after ACL reconstruction, those values may be helpful in determining the increase or decrease in initial tension at graft fixation. Less initial tension can be applied at graft fixation for the cases with large anterior tibial displacement before surgery.

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Declaration of competing interest

All authors have no conflicts of interest.

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