Factors Influencing the Progression of Patellofemoral Articular Cartilage Damage After Anterior Cruciate Ligament Reconstruction

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Background: Although anterior cruciate ligament reconstruction (ACLR) can restore the stability and function of the knee joint, patellofemoral joint cartilage damage still progresses. Currently, the clinically important factors that lead to the progression of patellofemoral articular cartilage damage are not fully understood.

Purpose: To investigate the factors that affect the progression of patellofemoral articular cartilage damage after ACLR.

Study Design: Cohort study; Level of evidence, 2.

Methods: Among 160 patients who underwent ACLR between January 2015 and December 2019, the authors evaluated 129 patients for at least 1 year after surgery. Within 1 week before ACLR and at the last follow-up, patients underwent subjective functional assessment and magnetic resonance imaging evaluations of articular cartilage damage (modified Outerbridge assessment). At the last follow-up, the side-to-side difference on KT-2000 arthrometer and bilateral quadriceps muscle strength were measured. Univariate and multivariate logistic regression analyses were performed.

Results: The mean follow-up was 24.69 ± 10.74 months. Progression of patellar cartilage damage from preoperatively to final follow-up was seen in 45 patients ($P < .001$). Logistic regression analysis revealed that the follow-up period ($P = .047$; odds radio (OR) = 0.953) (improvement of patellar cartilage damage with longer follow-up), partial lateral meniscal resection ($P = .004$; OR = 6.929), partial medial meniscal resection ($P = .004$; OR = 6.032), and quadriceps muscle strength <80% of the contralateral side ($P = .001$; OR = 4.745) were risk factors for the progression of patellar cartilage damage.

Conclusion: Cartilage damage at the patellofemoral joint, especially the patellar cartilage, still progresses after ACLR. At a mean follow-up of 24.69 months after ACLR, partial meniscal resection and quadriceps femoris muscle strength were found to be the main risk factors for the progression of patellofemoral articular cartilage damage after ACLR.

Keywords: anterior cruciate ligament reconstruction; knee; patellofemoral joint; patellar articular cartilage

Rupture of the anterior cruciate ligament (ACL) can cause knee joint instability and damage the articular cartilage.[6] ACL reconstruction (ACLR) can restore the stability of the knee joint and relieve patients' clinical symptoms as well as improve motor function.[25] Although a study has reported the development of tibiofemoral osteoarthritis after ACLR, 11% to 90% of patients develop patellofemoral arthritis after ACLR.[13] Imaging patellofemoral osteoarthritis may be more common than tibiofemoral osteoarthritis and is associated with worse knee-related symptoms, including anterior knee pain and decreased functional performance.[13] Gong et al[7] reported the occurrence of patellofemoral articular cartilage damage at an average follow-up of 17.3 months from single-bundle reconstruction of the ACL to the second arthroscopy.

Nakamae et al[18] reported that 174 patients underwent a second arthroscopy after an anatomic ACLR. Variables such as age, sex, body mass index, ACLR technique, and meniscal conditions were included in the regression analysis for progression of articular cartilage damage in the femoral condyle and tibial plateau. The authors found that partial meniscal resection was closely related to the progression of articular cartilage damage. Niki et al[19] analyzed the factors that affect anterior knee pain after ACLR and concluded that knee extension deficits are an important risk factor for knee pain before 3 months postoperatively.

The Orthopaedic Journal of Sports Medicine, 10(7), 23259671221108362
DOI: 10.1177/23259671221108362

Although patellofemoral articular cartilage damage could lead to anterior knee pain,[12,15,16] their study did not directly investigate the factors affecting the progression of this damage.

At present, the factors that affect the progression of patellofemoral articular cartilage damage after ACLR are not fully understood, and a more comprehensive analysis is lacking. To address this gap in knowledge, this study aimed to explore the factors that affect progression of patellofemoral cartilage damage after ACLR.

METHODS

Participants

This study was approved by the ethics committee of our hospital, and all participants signed an informed consent form before participating. All patients who underwent ACLR between January 2015 and December 2019 were invited to participate in this study. Included were patients who underwent single-bundle ACLR, with no history of surgery performed on the affected knee, with a normal contralateral knee, and with no posterior cruciate ligament insufficiency. Excluded were patients with lateral discoid meniscus, those with grade 3 medial or lateral instability,[11] and those who underwent ACLR combined with articular cartilage surgery. Patient selection details are illustrated in Figure 1. At the final follow-up, 129 patients were included.

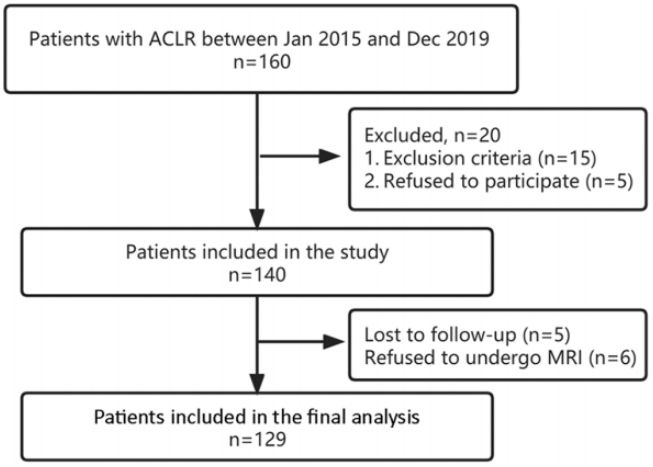

Figure 1. Flowchart of study enrollment. ACLR, anterior cruciate ligament reconstruction; MRI, magnetic resonance imaging.

Surgical Technique

A senior surgeon performed all surgeries using the arthroscopic single-bundle autologous hamstring tendon ACLR technique. Anatomic reconstruction technology was employed to create tibial and femoral bone canals. After pulling the graft into the bone canal, the surgeon used the EndoButton fixation device (Smith & Nephew) to fix the femoral side, whereas the tibial side was fixed with absorbable compression screws (Smith & Nephew). The meniscal damage was repaired via meniscal repair, meniscal file, or a partial meniscal resection. Radial tears, horizontal tears, or tears at the edges of the surrounding menisci were treated with a partial meniscal resection. If the longitudinal tear was in the red-red or red-white zone, the total internal repair technique of the arthroscopic suture system (FasT-Fix; Smith & Nephew) was used. A meniscal file was used to treat minor meniscal injuries.

After the surgery, the knee joint was fixed in the extension position via a brace. Four days later, the patients started knee flexion exercises and weightbearing which was gradually increased, with knee flexion at 90° in the first week and at 120° with full weightbearing after 6 weeks. The use of a knee brace was not required at home. Knee flexion had returned to normal at 8 to 12 weeks after the surgery. The patients were permitted to start jogging without a brace at 3 months postoperatively and to run, jump, and swim at 4 to 6 months postoperatively. A special adaptability training was conducted for 3 months, such that the patient could participate in intense special training and sports competitions at 10 months after the surgery.

Evaluation of Articular Cartilage Damage

Magnetic resonance imaging (MRI) evaluation of articular cartilage damage was performed using the modified Outerbridge grading system. The modified Outerbridge score was denoted as follows: 0, intact cartilage with normal signal; 1,

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Final revision submitted March 9, 2022; accepted April 8, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: This study was supported by the Hainan Provincial Natural Science Foundation of China (grant No. 821MS127). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the ethics committee of Hainan General Hospital.

increased signal intensity with no loss of cartilage thickness; 2, loss of <50% of the cartilage thickness; 3, loss of >50% of the cartilage thickness without exposed bone; and 4, full-thickness cartilage loss with exposed bone.[21] The progression of cartilage damage was defined as any increase in Outerbridge score from within 1 week before ACLR to the last follow-up. All of the measurements were taken by 3 experienced radiologists who were blinded to the patient's condition, and repeated measurements were performed at 2 time points that were at least 1 month apart.

MRI was performed via a 3.0-T MRI system (Magnetom Skyra; Siemens Healthcare) using a phased-array knee coil. Patients were placed in the supine position with the knee fully extended. The MRI parameters included sagittal T1 fast spin echo (FSE), sagittal fat-saturated proton density–weighted FSE, coronal fat-saturated blade FSE, and transverse fat-saturated proton density-weighted FSE (Appendix Table A1).

Clinical Function Assessments

At 1 week before the ACLR and at the last follow-up, the Lysholm scale,[1] International Knee Documentation Committee,[4] and Tegner[1] scores were used for functional assessment by an experienced orthopaedic surgeon (H.H.) on the same day.

At the last follow-up, the patients underwent bilateral knee examination using a KT-2000 arthrometer (MedMetric). The side-to-side anterior tibial translation difference, measured using a force of 133 N at 20° of knee flexion, was recorded.[20]

A Biodex System III isokinetic tester (Biodex Medical Systems) was used to perform isokinetic muscle strength tests on both quadriceps femoris muscles of each patient at the last follow-up. The peak torque (PT) of the quadriceps femoris (representing the maximum strength of the muscle) was recorded. The PT ratio of the quadriceps femoris was calculated as follows: affected side/healthy side. It was then divided into ratios <80% and ≥80%.[26] This study measured the muscle strength at an angular velocity of 60 deg/s.[20]

Statistical Analysis

SPSS Statistics Version 19.0 (IBM Corp) was used for statistical analysis between patients who showed progression of cartilage damage and those who did not. Univariate analysis was first used to analyze the risk factors that were considered to affect the progression of cartilage damage. The chi-square test or Fisher exact test was used to compare qualitative variables, and the independent-samples Student *t* test or 2-sample Wilcoxon rank sum test was used to compare quantitative variables. Multiple logistic regression analysis was used to examine the correlation among the identified factors, and the risk was estimated using odds ratios with 95% CIs. The significance threshold of the test was set at $P < .05$. The interobserver and intraobserver reliability for the MRI evaluation of articular cartilage damage were assessed using the intraclass correlation coefficient (ICC); reliability was interpreted as poor if ICC <0.4, marginal if $0.4 \leq \text{ICC} \geq 0.75$, and good if ICC >0.75.

We calculated a priori the sample sizes needed to achieve sufficient power for comparison of quadriceps strength between the patients with cartilage damage progression (observation group) and those without (control group). Pre-experiment results showed that the proportion of patients with a PT ratio of the quadriceps femoris <80% was 40% in the control group and 70% in the observation group. For hypothesis testing, type 1 error (α) was set as .05 using a 2-sided test and type 2 error (β) was set as 0.1 (ie, power = 0.9). The sample size of the 2 groups was set in a 2:1 ratio, and the sample sizes calculated using PASS software (Version 15.0; NCSS) were 84 for the control group and 42 for the observation group.

RESULTS

A total of 129 participants between the ages of 18 and 46 years (mean age, 26.98 years) were included in the final follow-up (47 female and 82 male patients). The mean follow-up was 24.69 ± 10.74 months (range, 12-50 months). The data of the participants are shown in Table 1.

A total of 45 patients had progression of patellar cartilage damage on MRI scans from within 1 week before ACLR to the last follow-up, and the difference was statistically significant ($P < .001$) (Appendix Table A2). In addition, 18 patients had MRI progression of trochlear cartilage damage from within 1 week before ACLR to the last follow-up, but the difference was not statistically significant ($P = .519$). In the MRI evaluation of articular cartilage damage, the interobserver and intraobserver reliability ICCs were 0.83 and 0.88, respectively, indicating good reliability.

Four factors were significantly related to the progression of patellar cartilage damage after ACLR: follow-up period ($P = .001$), PT ratio of the quadriceps femoris ($P < .001$), lateral meniscal injury ($P = .004$), and medial meniscal injury ($P = .046$) (Table 2). No factors were significantly related to the progression of the femoral trochlear cartilage damage after ACLR (Appendix Table A3).

In the logistic regression model, 4 previously identified factors related to the progression of patellar cartilage damage were introduced (ie, follow-up period, PT ratio of the quadriceps femoris, lateral meniscal injury, and medial meniscal injury). The results showed that follow-up period was significantly negatively correlated with the progression of patellar cartilage damage. In addition, a PT ratio of the quadriceps femoris <80%, partial meniscectomy of the lateral meniscus, and partial meniscectomy of the medial meniscus were significant risk factors for the progression of patellar cartilage damage (Table 3).

DISCUSSION

We found in this study that after ACLR, MRI examinations revealed postoperative progression of patellofemoral articular cartilage injuries, mainly on the patellar side, that was significantly related to postoperative time, meniscal damage, and quadriceps femoris muscle strength.

TABLE 1
Data of the Participants (N = 129)[a]

Variable	Value
Age, y	26.98 ± 6.05 (18-46)
Sex	
Female	47
Male	82
Body mass index	22.55 ± 3.80 (16.30-29.00)
Waist circumference, cm	77.49 ± 5.36 (61-95)
Metabolic syndrome	
Yes	0
No	129
Exercise[b]	
Yes	101
No	28
Hypertension	
Yes	5
No	124
Diabetes	
Yes	2
No	127
Smoker	
Yes	18
No	111
Surgical delay, wk	55.73 ± 62.83 (1-500)
Follow-up period, mo	24.69 ± 10.74 (12-50)
Lateral meniscus	
Normal	51
Minor damage	27
Meniscal repair	32
Partial meniscectomy	19
Medial meniscus	
Normal	62
Minor damage	28
Meniscal repair	15
Partial meniscectomy	24

[a]Values are presented as mean ± SD (range) or frequency.
[b]Regular exercise: ≥3 episodes per week, with at least 30 minutes of exercise per episode.

ACLR provides stability to the affected knee and further protects the knee cartilage from secondary damage caused by damaged ligaments.[3,7,18,26] However, there is evidence that ACLR cannot completely prevent the progression of osteoarthritis.[2,23] Meniscectomy is recognized as an important risk factor for posttraumatic osteoarthritis in ACLR.[10] A study by the Multicenter Orthopaedic Outcomes Network Knee Group[17] of 421 patients with follow-up knee radiographs at least 2 years after ACLR showed that meniscal repair and partial meniscectomy were both associated with worse radiographic posttraumatic osteoarthritis in the medial and lateral compartments. Furthermore, meniscectomy had a greater effect on worse posttraumatic osteoarthritis than did meniscal repair. A systematic review by van Meer et al[24] confirmed the importance of preservation of the meniscus for preventing development of osteoarthritis in patients who underwent ACLR. Our study showed that both medial and lateral partial meniscectomies were significant risk factors for the progression of patellar cartilage damage after ACLR.

Our study found that quadriceps muscle strength <80% of the contralateral side was associated with the progression of patellofemoral articular cartilage damage after ACLR. Restoring the muscle strength of the affected quadriceps femoris muscle to >80% of the strength of the quadriceps femoris muscle on the healthy side may reduce the occurrence and progression of patellar cartilage damage after ACLR. Keays et al[12] found that, in 56 patients who were followed up for an average of 6 years after ACLR, those with a smaller quadriceps femoris to hamstring muscle strength ratio had a higher incidence of osteoarthropathy in the tibiofemoral joint than in the patellofemoral joint. A study on knee osteoarthritis found that enhancing quadriceps femoris muscle strength can reduce the damage to the cartilage in the patellofemoral joint in patients with knee osteoarthritis; however, this has no obvious effect on the cartilage in the tibiofemoral joint.[22]

The study findings also showed that although recovery of quadriceps femoris muscle strength can significantly reduce the damage to the patellar cartilage after ACLR, it may not have a significant effect on damage to the trochlear cartilage. The reason for this finding is not clear. It may be related to the change in the quadriceps femoris muscle strength that subsequently affects the trajectory of the patella, which in turn affects the patellar articular cartilage damage. However, this conclusion requires further study.

After ACL damage, the levels of many cytokines, such as tumor necrosis factor α, interleukin 1β, and matrix metalloproteases 1 and 13, immediately increase in the joint.[9] Tumor necrosis factor α is related to the increase in apoptotic caspase pathways in the chondrocytes.[14] Although the levels of these cytokines slowly decline over time, ACL-deficient knees continue to show increased levels of inflammatory cytokines, at least 1 year after damage.[5,8] The adjustment of the initial inflammatory response after ACL damage may have a potentially lasting effect on early knee cartilage degeneration.[8] However, the potential reduction of the effect of ACL damage on joints after >1 year after ACLR remains to be further studied. Our study found that follow-up period (range, 12-50 months) was significantly negatively correlated with the progression of patellar cartilage damage, which may be because the effect of ACLR on articular cartilage metabolism is eliminated after >1 year postoperatively and because damaged cartilage repairs itself. Further studies are needed to confirm this finding, and a longer follow-up might provide clearer results.

Limitations

This study had several limitations. First, we lacked preoperative muscle strength assessments and preoperative KT-2000 arthrometer measurements for the patients, which might have affected the results. Second, the participants included those who had undergone a second MRI examination 1 year after surgery because they might have had knee discomfort and would prefer to undergo an MRI review at the time of follow-up. This preference to undergo a second MRI examination might have overestimated the changes in the cartilage. Third, the age range of the patients in our

TABLE 2
Factors Related to Progression of Patellar Cartilage Damage (Univariate Analysis)[a]

	Progression of Patellar Cartilage Damage			
	No (n = 84)	Yes (n = 45)	*t*	*P*
Age, y	26.89 ± 6.01	27.13 ± 6.20	−0.214	.831
Body mass index	22.55 ± 3.85	22.53 ± 3.73	0.040	.968
Surgical delay, wk	50.79 ± 55.83	64.96 ± 73.96	−1.223	.224
Follow-up, mo	26.73 ± 11.41	20.89 ± 8.19	3.347	**.001**
ATTD, mm	3.05 ± 1.24	2.91 ± 1.50	0.521	.604
Tegner score				
Within 1 wk before ACLR	2.00 ± 0.78	2.16 ± 0.93	−1.012	.313
Last follow-up	6.60 ± 1.03	6.29 ± 1.12	1.560	.121
IKDC score				
Within 1 wk before ACLR	42.30 ± 5.65	41.89 ± 6.21	0.378	.706
Last follow-up	89.32 ± 3.42	88.84 ± 5.11	0.632	.528
Lysholm score				
Within 1 wk before ACLR	51.48 ± 5.50	52.44 ± 5.35	−0.961	.338
Last follow-up	91.86 ± 3.58	91.76 ± 3.74	0.151	.880

	Patients With Progression of Patellar Cartilage Damage (n = 45)	χ^2	*P*
Sex		0.287	.592
Female	36.59		
Male	31.91		
PT ratio of the quadriceps femoris		12.198	**<.001**
<80%	50.85		
≥80%	21.43		
Lateral meniscal injury		13.514	**.004**
Normal	21.57		
Minor damage	33.33		
Meniscal repair	37.50		
Partial meniscectomy	68.42		
Medial meniscal injury		7.995	**.046**
Normal meniscus	27.42		
Minor damage	28.57		
Meniscal repair	40.00		
Partial meniscectomy	58.33		

[a]Data are presented as mean ± SD or percentage. Boldface *P* values indicate statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction; ATTD, anterior tibial translation side-to-side difference; IKDC, International Knee Documentation Committee; PT, peak torque.

TABLE 3
Logistic Regression Analysis of All Important Factors Identified in the Univariate Analysis[a]

	Regression Coefficient	*P*	OR (95% CI)
Follow-up period	−0.048	**.047**	0.953 (0.909-0.999)
PT ratio of the quadriceps femoris			
≥80%	—	—	1 (referent)
<80%	1.557	**.001**	4.745 (1.861-12.100)
Lateral meniscal injury			
Normal	—	—	1 (referent)
Minor damage	0.46	.444	1.585 (0.488-5.145)
Meniscal repair	0.931	.114	2.537 (0.799-8.055)
Partial meniscectomy	1.936	**.004**	6.929 (1.826-26.302)
Medial meniscal injury			
Normal	—	—	1 (referent)
Minor damage	0.144	.814	1.154 (0.348-3.827)
Meniscal repair	1.006	.155	2.734 (0.684-10.937)
Partial meniscectomy	1.797	**.004**	6.032 (1.765-20.609)

[a]Boldface *P* values indicate statistical significance ($P < .05$). OR, odds ratio; PT, peak torque. Dashes refer to reference.

study was large (18-46 years), which might have affected the results. However, the effect of age on the progression of cartilage damage was not significant. Finally, the time interval from the ACLR to the last follow-up was quite wide. However, our sample size did not allow us to analyze different potential characteristics at different time points.

CONCLUSION

Our findings suggest that damage of the patellofemoral articular cartilage is significantly aggravated after ACLR, which may manifest mainly in the patellar cartilage and may be closely related to postoperative time, quadriceps femoris muscle strength, and partial meniscal resection. The meniscus should be preserved as much as possible during the operation, and great importance should be focused on quadriceps femoris muscle strength exercises after surgery.

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APPENDIX

TABLE A1
Parameters for MRI Sequences[a]

	Sagittal T1 FSE	Sagittal Fat-Sat PD FSE	Coronal Fat-Sat Blade FSE	TRA Fat-Sat PD FSE
Repetition time, ms	500	3050	4000	3320
Echo time, ms	11	34	63	61
Field of view, cm	16	16	16	15
Section thickness, mm	3	3	3	3
Spacing, mm	1	1	1	1
Echo train length	1	8	15	11

[a]Fat-Sat, fat saturated; FSE, fast spin echo; MRI, magnetic resonance imaging; PD, proton density-weighted; TRA, transverse.

APPENDIX TABLE A2
Patellar and Trochlear Cartilage Damage According to Modified Outerbridge Grade[a]

	Patella			Trochlea		
	Within 1 wk Before ACLR	At Last Follow-up	*P*	Within 1 wk Before ACLR	At Last Follow-up	*P*
Outerbridge grade			**<.001**			.519
0	61 (47.29)	41 (31.78)		109 (84.50)	104 (80.62)	
1	47 (36.43)	46 (35.66)		11 (8.53)	20 (15.50)	
2	19 (14.73)	33 (25.58)		9 (6.98)	2 (1.55)	
3	2 (1.55)	8 (6.20)		0 (0)	3 (2.33)	
4	0 (0)	1 (0.78)		0 (0)	0 (0)	
Grade 0-1	—	15	—	—	14	—
Grade 0-2	—	5	—	—	0	—
Grade 1-2	—	16	—	—	1	—
Grade 2-3	—	8	—	—	3	—
Grade 3-4	—	1	—	—	0	—

[a]Data are presented as frequency (%). Boldface *P* value indicates statistical significance ($P < .05$). ACLR, anterior cruciate ligament reconstruction. Dashes indicate not applicable.

APPENDIX TABLE A3
Factors Related to Progression of Femoral Trochlear Cartilage Damage (Univariate Analysis)[a]

	Progression of Femoral Trochlear Cartilage Damage			
	No (n = 111)	Yes (n = 18)	*t*	*P*
Age, y	27.09 ± 6.07	26.28 ± 6.10	0.527	.599
Body mass index	22.48 ± 3.83	22.94 ± 3.65	–0.473	.637
Surgical delay, wk	52.09 ± 50.85	78.17 ± 111.23	–0.978	.341
Follow-up period, mo	25.14 ± 10.92	21.89 ± 9.29	1.195	.234
ATTD, mm	3.01 ± 1.30	2.94 ± 1.55	0.19	.85
Tegner score				
Within 1 wk before ACLR	2.01 ± 0.80	2.33 ± 0.97	–1.542	.126
Last follow-up	6.51 ± 1.03	6.33 ± 1.28	0.662	.509
IKDC score				
Within 1 wk before ACLR	42.47 ± 5.58	40.22 ± 7.04	1.524	.13
Last follow-up	89.13 ± 3.81	89.33 ± 5.58	–0.199	.842

(continued)

Appendix Table A3 (continued)

	Progression of Femoral Trochlear Cartilage Damage			
	No (n = 111)	Yes (n = 18)	*t*	*P*
Lysholm score				
Within 1 wk. before ACLR	51.76 ± 5.35	52.17 ± 6.19	–0.295	.769
Last follow-up	91.95 ± 3.41	91.00 ± 4.78	1.037	.302
	Patients With Progression of Femoral Cartilage Damage (n = 18)		χ^2	*P*
Sex			0.087	.768
Female	14.63			
Male	12.77			
PT ratio of the quadriceps femoris			3.692	.055
<80%	20.34			
≥80%	8.57			
Lateral meniscal damage			3.977	.264
Normal	7.84			
Minor damage	22.22			
Meniscal repair	12.50			
Partial meniscectomy	21.05			
Medial meniscal damage			5.692	.128
Normal	11.29			
Minor damage	14.29			
Meniscal repair	33.33			
Partial meniscectomy	8.33			

[a]Data are presented as mean ± SD or percentage. ACLR, anterior cruciate ligament reconstruction; ATTD, anterior tibial translation side-to-side difference; IKDC, International Knee Documentation Committee; PT, peak torque.