Association Between ACL Remnant Morphology and Meniscal Injuries: A Multicenter Cohort Study

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INTRODUCTION:

Anterior cruciate ligament (ACL) injuries are accompanied by meniscus injuries. Meniscal injuries contribute significantly to biomechanical deterioration of the knee and may accelerate the progression of osteoarthritis. Therefore, clarifying factors related to meniscal injuries associated with ACL-deficient knees is of clinical importance. The morphology of the ACL remnant has been reported to influence knee stability. However, the relationship between ACL remnant morphology types and meniscal injuries remains unclear.

We hypothesized that the incidence of meniscal injuries would vary according to the morphology of the ACL remnant. The purpose of this study was to investigate the relationship between ACL remnant morphology and the occurrence of medial and lateral meniscal injuries.

METHODS:

This is a retrospective multicenter cohort study approved by the institutional review board; all participants provided written informed consent. The data was prospectively collected from patients who underwent ACL reconstruction between October 2022 and November 2024 at the participating facilities. Patients with associated fractures, patients aged ≤10 years or ≥60 years, revision ACL reconstruction, previous surgeries on the affected knee, combined ligament injuries (PCL and/or grade 3 collateral ligament injuries), and radiographic evidence of osteoarthritic changes (Kellgren-Lawrence grade ≥2) were excluded. Demographic data, knee stability assessments, and intraoperative findings were collected.

ACL remnant morphology was classified into four types based on Crain's classification: type 1 (bridging between the posterior cruciate ligament and the tibia), type 2 (bridging between the roof of the intercondylar notch and the tibia), type 3 (bridging between the lateral wall of the intercondylar notch and the tibia), and type 4 (no substantial remnant). Meniscal injuries requiring repair or resection were defined as meniscal tears in this study.

Univariate and multivariate logistic regression analyses were performed to identify independent predictors of medial meniscus (MM) and lateral meniscus (LM) tears, adjusting for age, sex, body mass index (BMI), time from injury to surgery, Tegner Activity Scale (TAS), contralateral hyperextension, Lachman test grades, and Pivot shift test grades. Continuous variables were analyzed using one-way analysis of variance or the Kruskal–Wallis test, depending on the normality of the data. Categorical variables were analyzed using the chi-square test. Statistical analyses were conducted using JMP□, Version 18 (SAS Institute Inc., Cary, NC, 1989–2025), with statistical significance set at $p < 0.05$.

RESULTS:

Of the 335 initially identified patients, 29 were excluded based on predefined criteria, resulting in 306 patients included in the final analysis (Figure 1). The distribution of ACL remnant types was as follows: type 1 in 54 patients (17.6%), type 2 in 120 patients (39.2%), type 3 in 83 patients (27.1%), and type 4 in 49 patients (16.0%).

The Patient Characteristics was shown in Table 1. There were no significant differences among the four Crain groups regarding age, sex, BMI, TAS, or Lachman test grade. In contrast, significant differences were observed, time to surgery ($p = 0.009$), in the incidence of contralateral hyperextension ($p = 0.002$) and pivot shift test grade ($p = 0.01$) among the groups.

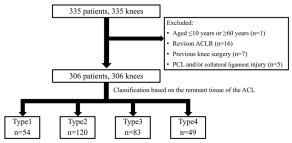
MM tears were identified in 114 patients (37.3%), and LM tears in 151 patients (49.3%). Significant differences in the incidence of medial meniscal tears were observed among Crain groups ($p = 0.003$), with tear rates of 40.7% for type 1, 35.8% for type 2, 25.3% for type 3, and 57.1% for type 4. No significant differences were noted among groups for lateral meniscal tears ($p = 0.55$) (Table 2).

Multivariate logistic regression analysis identified Crain classification as a significant predictor for medial meniscal tears. Compared to type 4, type 2 showed significantly lower odds of MM tear (odds ratio [OR], 0.42; 95% confidence interval [CI], 0.21-0.86; $p = 0.019$), as did type 3 (OR, 0.27; 95% CI, 0.12-0.60; $p = 0.001$). For lateral meniscal tears, independent predictors included higher BMI (OR per unit increase, 1.07; 95% CI, 1.01-1.14; $p = 0.034$) and higher TAS scores (OR per unit increase, 1.18; 95% CI, 1.01-1.39; $p = 0.036$) (Table 3).

DISCUSSION AND CONCLUSION:

ACL remnant morphology is significantly associated with the risk of MM tears, with type 4 remnants presenting a notably higher risk compared to types 2 and 3. Conversely, LM tears appear to be primarily influenced by patient-related factors such as BMI, and activity level, rather than by ACL remnant morphology. These findings provide valuable insight into the influence of ACL injury on the development of meniscal tears.

Figure 1. Flowchart of Study Participants.



After excluding ineligible cases from the initial 335 cases, patients were classified into four groups based on the remnant tissue of the ACL.
ACLR: anterior cruciate ligament reconstruction; PCL: posterior cruciate ligament

Table 1. Patient Characteristics for All Cases and by Group.

	All case (n = 306)	Type1 (n = 54)	Type2 (n = 120)	Type3 (n = 83)	Type4 (n = 49)	p-value
Age, y	28.1 ± 12.6	28.0 ± 13.3	28.2 ± 12.4	29.5 ± 12.3	25.8 ± 13.0	0.18
Sex						0.92
Male	156 (51.0%)	26 (48.2%)	61 (50.8%)	42 (50.6%)	27 (55.1%)	
Female	150 (49.0%)	28 (51.8%)	59 (49.2%)	41 (49.4%)	22 (44.9%)	
BMI, kg/m^2	23.9 ± 4.1	23.5 ± 3.3	24.0 ± 4.0	24.3 ± 4.2	23.7 ± 4.8	0.70
Time to surgery, months	2 (1–6)	3 (2–10)	2 (1–4)	2 (1–3)	4(1–19)	**0.009**
Tegner Activity Scale	6 (5–7)	6 (5–7)	7 (6–7)	6 (4–7)	7 (5–7)	0.14
Knee hyperextension	51 (16.7%)	8 (14.8%)	15 (12.5%)	9 (10.8%)	19 (38.8%)	**0.001**
Lachman test						0.30
Low grade (A or B)	208 (65.4%)	35 (64.8%)	75 (62.5%)	61 (73.5%)	29(59.2%)	
High grade (C or D)	106 (34.6%)	19 (35.2%)	45 (37.5%)	22 (26.5%)	20(40.8%)	
Pivot shift test						**0.01**
Low grade (A or B)	175 (57.2%)	32 (59.3%)	67 (55.8%)	57 (68.7%)	19 (38.8%)	
High grade (C or D)	131 (42.8%)	22 (40.7%)	53 (44.2%)	26 (31.3%)	30 (61.2%)	

Data are presented as numbers (n) or ratios (%), and medians with Interquartile range.
A bold number means a significant difference (< 0.05).
BMI: body mass index.

Table 2. Meniscus Injury in this Study and by Group

	All cases (n = 306)	Type1 (n = 54)	Type2 (n = 120)	Type3 (n = 83)	Type4 (n = 49)	p-value
Meniscal injury						
Medial meniscal tear	114 (37.3%)	22 (40.7%)	43 (35.8%)	21 (25.3%)	28 (57.1%)	**0.003**
Lateral meniscal tear	151 (49.3%)	24 (44.4%)	59 (49.2%)	46 (55.4%)	22 (44.9%)	0.55

Data are presented as numbers (n) and ratios (%). **A bold number** means a significant difference (< 0.05).

Table 3. Multivariate Logistic Regression Analysis for the Meniscal Injury.

	MM tear		LM tear	
Variables	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Age	1.02 (1.00–1.04)	0.071	0.99 (0.97-1.01)	0.46
Sex				
Male	1.00 (Reference)		1.00 (Reference)	
Female	1.34 (0.79–2.27)	0.27	1.33 (0.80-2.20)	0.27
BMI	1.02 (0.96-1.08)	0.59	1.07 (1.01–1.14)	**0.034**
Time to surgery [A]	1.00 (1.00–1.00)	0.74	1.00 (1.00–1.00)	0.32
Tegner Activity Scale	1.09 (0.93–1.29)	0.29	1.18 (1.01–1.39)	**0.036**
Knee hyperextension	1.00 (0.50-1.98)	0.99	1.21 (0.62-2.37)	0.57
Lachman test grade [C]				
Low grade (A or B)	1.00 (Reference)		1.00 (Reference)	
High grade (C or D)	1.10 (0.65–1.85)	0.73	1.65 (1.00-2.74)	0.052
Pivot shift test grade [C]				
Low grade (A or B)	1.00 (Reference)		1.00 (Reference)	
High grade (C or D)	1.62 (0.97-2.69)	0.063	1.14 (0.70-1.86)	0.61
Crain classification				
Type 4	1.00 (Reference)		1.00 (Reference)	
Type 1	0.56 (0.25-1.28)	0.17	1.16 (0.51-2.65)	0.72
Type 2	0.42 (0.21-0.86)	**0.019**	1.25 (0.61-2.55)	0.54
Type 3	0.27 (0.12-0.60)	**0.001**	1.82 (0.84-3.92)	0.13

Odds ratios were adjusted for all other predictors in the table.
A bold number means a significant difference (< 0.05). Statistical significance for the Crain classification was determined after adjustment for multiple comparisons using Holm's method.
MM: medial meniscus; LM: lateral meniscus; OR: odds ratio; CI: confidence interval;
BMI: body mass index.