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Femoral attachment of anterior cruciate ligament remnant tissue influences the stability of the anterior cruciate ligament-injured knee in patients over 40 years old

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1. Introduction

The uses of anterior cruciate ligament (ACL) remnant tissue as a potential accelerant of graft remodeling[1–3] and promoter of better knee stability[4] have recently attracted attention. However, ACL remnant tissue is generally resected during ACL reconstruction to provide a clear visual field.[5] Several investigators have therefore developed and implemented a procedure that includes remnant tissue preservation and have subsequently observed better clinical outcomes compared to conventional reconstruction.[6–8]

Even years after an injury, ACL remnant tissue contains proprioceptive mechanoreceptors; therefore, it is considered as a potential source of re-innervation.[5] However, contrasting reports suggest that the elapsed time after injury might affect the number of persistent mechanoreceptors[9] and that the biomechanical contribution of remnant tissue is lost by one year post injury.[10] Furthermore, the ACL remnant tissues of adolescent patients were reported to exhibit a significantly higher differentiation potential,[11] and in a rat model of ACL reconstruction, remnant tissues from younger animals were found to enhance early bone tendon healing better than tissues from older animals.[12] These findings suggest that surgeons should consider the patients' age and timing of injury when planning ACL reconstruction with remnant tissue preservation, and raise concerns regarding whether remnant tissue can accelerate the graft remodeling phase and promote recovery and stability across all ages.

Notably, the stability of an ACL-injured knee appears to depend on the site of attachment of the femoral end of the remnant tissue.[10] However, despite the recent interest in ACL reconstruction with remnant tissue preservation,[7,13,14] there are no reports investigating how the combined effects of patient age and femoral attachment site influence the stability of an ACL-injured knee. This study was conducted to address a hypothesis that the patient's age and femoral ACL remnant attachment site would influence stability in an ACL-deficient knee.

2. Methods

2.1. Patient selection

The Institutional Review Board of the ethical committee of our institution approved this single-center retrospective comparative study. The electronic medical records of patients with unilateral ACL injury who met the indications for arthroscopic reconstruction and underwent ACL reconstruction at our institution from March 2014 to March 2015 were retrospectively investigated. All patients were diagnosed with ACL injury on the basis of clinical findings, such as a positive Lachman test[15] and MRI findings. Physical examinations and interpretations of radiological evaluations were performed by orthopedic specialists authorized by Japanese Orthopedic Association and highly experienced knee surgeons who did not co-author the present study. Patients with concomitant ligament injuries treated via simultaneous reconstruction, associated fractures of the femur or tibia, severe chondral lesions, obvious varus or valgus knee osteoarthritis, and a previous history of knee

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surgery were not included in this study because of the potential effects on ACL remnant tissue. Patients who had not undergone an initial MRI at the outpatient center within 1 year post injury were also excluded because Nakamae et al reported that the biomechanical contribution of the ACL remnant tissue would be lost 1 year post injury.[10]

First, the authors retrospectively investigated the ACL remnant tissue morphology, volume, continuity, and tension by reviewing arthroscopic videos recorded at the time of ACL reconstruction surgery[10] per the Crain classification.[16] All the ACL remnant tissue exhibited weak tension when probed.

The patients' characteristics are listed in Table 1. Patients were divided by age into the following two groups for analytical purposes: Group I, ≤39 years and Group II, ≥40 years. The authors divided the patients at the age of 40 for the following reasons. First, Wang et al and Wierer et al reported that patients >40 years of age would achieve comparable clinical outcomes after ACL reconstruction as younger patients.[17,18] Second, the authors the present study attempted to clarify the laxity of ACL injured knee according to age and location of the femoral attachment of ACL remnant tissue.

2.2. Clinical evaluations

In addition, patients were compared with respect to the IKDC subjective scale[19] and Tegner activity scale.[20] During preoperative outpatient visits, patients were asked to complete the Lysholm score, IKDC subjective scale, and Tegner activity scale by nurses who were not involved in this study.

2.3. Image assessment

The preoperative SSD was evaluated using Telos™ (Telos GmbH, Laubscher, Holstein, Switzerland).[21] Each patient was asked to lay on the bed with their knee flexed at 20 degrees while a 15-kg (147 N) anterior force was applied to the tibia relative to the femur, and two lines were defined. First, the tibial line was defined as tangent to posterior edge of the medial tibial plateau and perpendicular to the line tangent to the medial tibial plateau. Second, the femoral line was defined as tangent to the posterior edge of the medial femoral condyle and parallel to the tibial line. This distance was measured using a Picture Archiving and Communicating System (PACS; 0.01-mm precision) by experienced orthopedic surgeons who were not involved in this study (Fig. 1). The radiation exposure per patient during this process ranged from 0.1 to 0.15 mSv, similar to that of conventional radiographic imaging.

MRI examinations were performed on a 1.5-T instrument (Echelon RX; Hitachi Corporation, Tokyo, Japan), with the knee placed in a neutral position in an extremity coil. Sagittal images were acquired using fast spin-echo (FSE) proton density-weighted imaging (PDWI), with repetition time (TR) and echo time (TE) values of 2000 and 10 milliseconds, respectively. The signal-to-noise quotients (SNQs) in the tibial, mid, and femoral portions of the injured ACL were calculated using the region of interest (ROI) technique.[22,23] A ROI of the quadriceps femoris tendon signal at the upper patellar limit level and the background signal at approximately 2 cm anterior to the patellar tendon were measured to normalize the signal intensity of the ACL remnant tissue. All ROIs were circular, with a diameter of 3.3 mm. All five ROI measurements were performed using a PACS monitor (GE Healthcare, Barrington, IL, USA) and mouse cursor (Fig. 2) and the following equation[22] was used to quantify the SNQ from five ROI measurements: SNQ = (ACL remnant tissue signal −quadriceps femoris signal)/background signal. For evaluating the remnant intensity on MRI, intraobserver and interobserver reproducibility were evaluated using the intraclass correlation coefficient (ICC).

Table 1
Patient characteristics.

Parameters	
Sex (M/F)	61/65
Affected side (R/L)	49/77
Age (years)	28.3 (13.7) (12–70)
Time to MRI (weeks)	6.6 (9.2) (0–52)

Data are expressed as mean (standard deviation).

2.4. Statistics

All data from statistical analyses are presented as means ± standard deviations. A one-way analysis of variance (ANOVA) with post hoc analysis was used to evaluate differences or correlations between groups. The Mann–Whitney U test was used to evaluate differences in non-parametric variables between groups. All statistical analysis were performed using EZR (http://www.jichi.ac.jp/saitama-sct/SaitamaHP.files/statmed.html),[24] and the significance level was set at $P < 0.05$. Assuming an α error of 0.05, β error of 0.20, and effect size of 0.25, the authors calculated an adequate sample size of 128 using G* Power 3.1 (Franz Paul, Kiel, Germany). The power analysis revealed a β error of 0.202 and calculated power of 0.797.

3. Results

Initially, 165 patients were selected from the medical records; of these, 20 patients met the exclusion criteria and were eliminated. Therefore, 145 patients were enrolled for further evaluation. Finally, 126 patients with Crain type 1–3 remnants of adequate volume and continuity were included in this study. Nineteen patients with type 4 remnants were excluded because insufficient remnant tissues were available for radiological assessment.

Of the 126 patients in the final evaluation, 93 (46 men, 47 women) and 33 (15 men, 18 women) patients were classified into Groups I and II, respectively. The groups did not differ significantly with respect to the male/female ratio, elapsed time from injury to MRI evaluation, Lysholm score, and IKDC subjective scale score (Table 2).

Group I included 11 Crain type 1, 46 Crain type 2, and 36 Crain type 3 cases, whereas Group II included 9 Crain type 1, 11 Crain type 2, and 13 Crain type 3 cases. There were no significant differences regarding the Crain classification distribution between the groups ($P = 0.08$) (Table 3). Group I had a significantly higher Tegner activity scale score (7.4 ± 2.1) vs. Group II (4.8 ± 2.0) ($P < 0.0001$) (Table 2). However, the groups did not differ significantly in terms of SNQs in the tibial, mid, and femoral portions of the ACL remnant (Table 4). Both intraobserver variability (mean intraclass correlation coefficient, 0.902; range, 0.840–0.930) and interobserver variability were excellent (mean intraclass correlation coefficient, 0.880; range, 0.840–0.900).

Group I had a significantly higher preoperative SSD (6.8 ± 3.6 mm) than Group II (7.6 ± 4.3 mm) ($P = 0.016$). By classification, in Group I, the SSDs were 8.9 ± 5.5 mm in Crain type 1, 6.5 ± 3.0 mm in Crain type 2, and 6.6 ± 3.6 mm in Crain type 3 cases. No significant differences in SSD were observed among the three subgroups ($P = 0.121$). In contrast, significant differences were observed among the three subgroups of Group II ($P = 0.0040$), and a post hoc analysis revealed that the SSD was significantly greater in Crain type 1 cases (14.9 ± 5.7 mm), compared with Crain type 2 (7.7 ± 3.9 mm; $P = 0.016$) and Crain type 3 (6.4 ± 3.3 mm; $P = 0.0028$; Fig. 3) cases. Additionally, among Crain type 1 cases, the

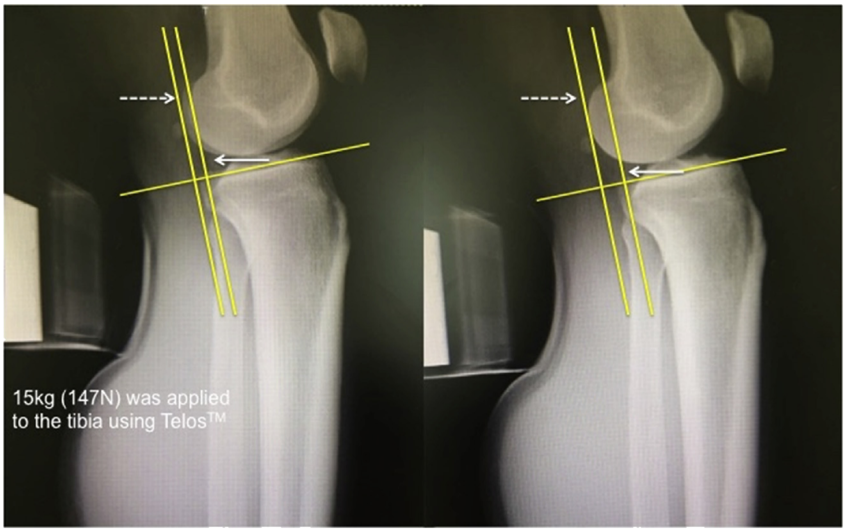

Fig. 1. Representative images of preoperative SSD evaluation using Telos™. White arrows indicate the tibial line tangent to posterior edge of the medial tibial plateau and perpendicular to the line tangent to the medial tibial plateau. White dotted arrows indicate the femoral line tangent to posterior edge of the medial femoral condyle and parallel to the tibial line. The distance between white arrow and white dotted arrow indicates an anterior laxity. SSD is the difference of anterior laxities between right and left knee.

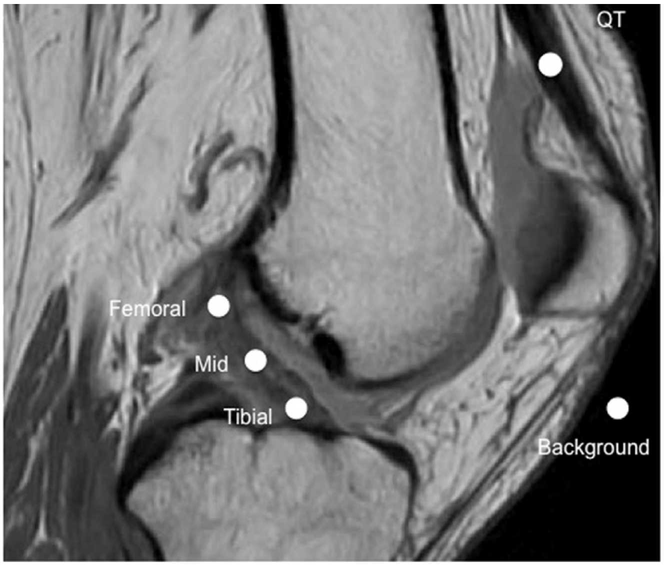

Fig. 2. Sagittal magnetic resonance image of the knee shows the positions of the following five evaluated regions: Tibial portion, Mid portion, Femoral portion of ACL remnant tissue, Quadriceps femoris tendon, and Background. Quantification of SNQ from five ROI measurements using the following formula: SNQ = (ACL remnant tissue signal − quadriceps femoris signal)/background signal.

Table 2
Male/female ratio, time from injury to MRI evaluation, Lysholm score, and IKDC subjective scale score between the groups.

Parameters	Group I (n = 93)	Group II (n = 33)	P value[a]
Age	21.5 (7.2)	47.7 (7.4)	<0.0001
Sex (M/F)	46/47	15/18	0.847
Time to MRI (weeks)	6.5 (8.8)	6.9 (10.6)	0.619
Lysholm score	70.7 (21.8)	72.9 (27.8)	0.694
IKDC subjective scale	50.4 (15.1)	50.3 (20.9)	0.075
Tegner activity scale	7.4 (2.1)	4.8 (2.0)	<0.0001

Data are expressed as mean (standard deviation).
[a] Comparison between Groups by use of one-way ANOVA.

SSD was significantly greater in Group II than in Group I ($P = 0.049$), whereas no significant differences were observed for Crain type 2 and type 3 cases.

4. Discussion

This study revealed significant differences in the preoperative SSD among Group I (younger) and Group II (older) patients. On the other hand, significant differences were not observed among the groups with respect to Crain type 2 and type 3 ACL remnants, which retained relatively better anterior stability. On the other hand, among Crain type 1 cases, those in Group II had a significantly greater preoperative SSD than Group I, suggesting that age may influence the laxity of an ACL injured knee with Crain type 1 remnant tissue.

MRI is highly sensitive and specific for the diagnosis of ACL injuries,[25] its usefulness with respect to the remnant tissue is controversial. Although a previous report suggests that diagnostic preoperative MRI provides limited information about the remnant tissue,[26] other researchers describe MRI as an important tool for predicting patterns of ACL remnant tissues[10] or bundle injuries with satisfactory precision.[26] In this study, MRI findings and videos of arthroscopic assessments were used to evaluate the remnant tissue volume, continuity, and tension.

On MRI, the normal ACL appears as a band with low signal intensity,[27,28] whereas the injured ACL, which impairs anteroposterior knee stability, exhibits a high signal indicative of fluid and hemorrhage confined to the intact synovial sheath.[29,30] The authors of this study observed no significant differences in SNQ between the two age-related groups when using the ROI technique, suggesting that a factor other than the SNQ of the ACL remnant tissue had influenced the difference in SSD between the groups.

Table 3
Distribution of Crain classification between the groups.

Crain classification	Type 1	Type 2	Type 3	P value
Group I	11	46	36	0.08
Group II	9	11	13	

Table 4
Results of the SNQ of ACL remnant tissue between the groups.

Parameters	Group I (n = 93)	Group II (n = 33)	P value[a]
Femoral	34.4 (19.8)	31.2 (16.0)	0.250
Mid	34.7 (22.4)	28.6 (17.9)	0.109
Tibial	27.0 (16.1)	23.0 (12.8)	0.118

Data are expressed as mean (standard deviation).

[a] Comparison between Groups by use of one-way ANOVA.

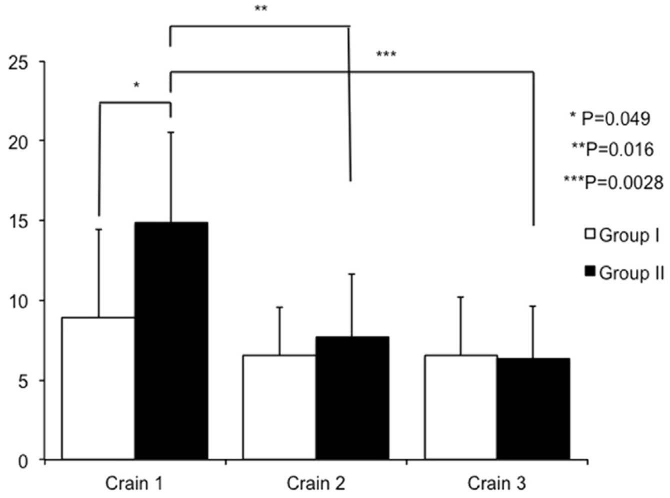

Fig. 3. Evaluation of SSD according to Crain classification between the groups.

According to the findings of the present study, Groups I and II differed significantly with respect to only Tegner activity scale score. Although the Tegner activity scale is used to determine a patient's physical activity level, the main advantage of this scale is its ability to evaluate changes in the same patient over time, rather than to compare different patients.[31] Therefore, the study results could not indicate that the activity level influenced the stability of a Crain type 1 ACL remnant tissue in which the remnant–femoral attachment adhered to the PCL rather than the femur.

This study had several limitations. First, ROI was evaluated using only sagittal MRI images rather than oblique coronal or oblique sagittal images, which have been reported to distinguish anteromedial and posterolateral bundles with greater accuracy.[32] In addition, it is relatively difficult to diagnose the small disruption of a proximally torn ACL that has adhered to the PCL or maintained gross alignment using a sagittal sequence. In such cases, axial or coronal plane images may allow a more accurate diagnosis.[33] Arthroscopic assessment was also used to evaluate the morphology of the ACL remnant tissue. Second, the authors did not include rotatory stability findings obtained during outpatient examinations because this parameter is dependent on the examiner's experience and therefore cannot be qualitatively evaluated.[34] However, a pivot shift test, conducted using a three-dimensional electromagnetic measurement system under general anesthesia, revealed a lack of significant differences in the Crain classification-based results.[35] Third, the investigation did not include chronic cases in which patients underwent MRI more than 1 year post injury because of a previous report that the biomechanical contribution of the ACL remnant tissue would be lost after this time point.[10] Fourth, it would be helpful to further divide cases by age (e.g., <25, 25–40, 40–55 years). However, the present sample size was too small to allow this type of division. This will remain a point of interest in future studies. Lastly, the follow-up duration was short.

However, beyond these limitations, this study clarified that among ACL-injured patients with Crain type 1 remnants, knee laxity was greater among those older than 40 years, than among younger patients. These results may affect postoperative knee stability in patients who have undergone ACL reconstruction with remnant tissue preservation. Further studies are needed to clarify whether the factors identified in our study truly influence postoperative stability, bone-tendon healing, and proprioception recovery.

Ethics approval

The Institutional Review Board of the ethical committee of Zenshukai Hospital Gunma Sports Medicine Research Center approved this retrospective comparative study (approval number: 160614).

Consent to publish

Not applicable.

Conflicts of interest

The authors have declared no financial conflicts of interest with respect to their authorship and publication of this work.

Author's contributions

TT designed the study and acquired, analyzed, and interpreted data. TO, MK, and KT participated in study conception and design and revision of the data and manuscript. All authors read and approved the final manuscript.

Availability of data and materials

The datasets used in the current study are available from the corresponding author, Tsuneari Takahashi, MD, PhD in response to reasonable requests.

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