



Medial Meniscal Ramp Lesion Repair Concomitant With Anterior Cruciate Ligament Reconstruction Did Not Contribute to Better Anterior Knee Stability and Structural Properties After Cyclic Loading: A Porcine Model

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Purpose: To investigate the biomechanical efficacy of medial meniscal ramp lesion (MMRL) repair in anterior cruciate ligament (ACL) reconstruction regarding the graft protection effect after cyclic loading. **Methods:** Specimens were randomized into 2 groups: (1) ACL reconstruction with unaddressed MMRL (Group U; n = 10), and (2) ACL reconstruction with repaired MMRL (Group R; n = 12). The specimens were tested cyclically (2,000 cycles, 0-40 N, 100 mm/min) in the direction of the native ACL and loaded to failure (100 mm/min) on a tensile tester. Statistically significant differences between the structural properties (length changes and anterior translations at the 100th, 500th, 1,000th, 1,500th, and 2,000th cycles, upper yield load, maximum load, linear stiffness, and elongation at failure) under cyclic loading and single-cycle loading were analyzed. **Results:** There were no significant differences in length changes and anterior translations at the 100th, 500th, 1,000th, 1,500th, and 2,000th cycles. There were no significant differences in upper yield load (82.4 ± 31.2 N in Group U, 90.0 ± 38.5 N in Group R, $P = .62$), maximum load (109.9 ± 28.6 N in Group U, 124.0 ± 56.4 N in Group R, $P = .48$), linear stiffness (12.1 ± 4.7 N/mm in Group U, 12.5 ± 4.3 N/mm in Group R, $P = .84$), or elongation at failure (13.5 ± 7.3 mm in Group U, 16.6 ± 7.5 mm in Group R, $P = .30$). **Conclusions:** Simultaneous MMRL repair at the time of ACL reconstruction did not decrease length changes and anterior translations during cyclic loading. In addition, simultaneous MMRL repair at the time of ACL reconstruction did not contribute to better postoperative structural properties. **Clinical Relevance:** Simultaneous MMRL repair at the time of ACL reconstruction does not show a graft protective effect after cyclic loading. Graft elongation may occur during early rehabilitation.

The medial meniscus plays an important role as a secondary restraint against anterior tibial translation, whereas the anterior cruciate ligament (ACL) acts as a primary restraint.¹ Medial meniscal ramp lesions (MMRLs) have recently attracted attention. An MMRL is defined as a peripheral meniscocapsular

detachment of the posterior medial meniscus² concomitant with ACL injury. Repair of the MMRL is reported to be biomechanically important for restoring knee kinematics and preventing increased strain in the ACL graft,³ even though it has been reported that MMRL may not have an immediate bearing on the risk

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for early graft failure and development of osteoarthritis in the setting of ACL reconstruction.⁴ Cyclic loading was reported to decrease the initial stiffness of the ACL-reconstructed knee.⁵ The effect of MMRL repair on the MM function as a secondary restraint during cyclic loading still remains unclear. There also remains a question about whether MMRL repair in the setting of ACL reconstruction could result in increased stiffness, less graft elongation, and increased ultimate load to failure after cyclic loading compared with unrepaired ramp lesions in the setting of ACL reconstruction. The purpose of this biomechanical study was to investigate the biomechanical efficacy of MMRL repair in ACL reconstruction regarding the graft protection effect after cyclic loading. We hypothesized that simultaneous MMRL repair during ACL reconstruction would result in better structural properties after cyclic anterior loading than those of unaddressed MMRL repair in ACL reconstruction.

Methods

Study Design

Animal experiments were performed at our institution's biomechanics laboratory and conducted in accordance with the regulations of the Animal Care and Use Committee at our institution. Ethical approval by the Committee was waived due to the *ex vivo* nature of this study. This study used 22 fresh porcine knees (age: 6 months, weight range: 100-120 kg; Tokyo Shibaura Zouki, Tokyo, Japan). The tibial neck and femoral head

were cut off, and the bone shafts were set into aluminum tubes with cement.^{6,7} Each specimen was randomly assigned to a group: (1) ACL reconstruction with unaddressed MMRL (Group U; $n = 10$) or (2) ACL reconstruction with repaired MMRL (Group R; $n = 12$).

Surgical Procedures

ACL Reconstruction and MMRL Procedure

In each group, we used a previously reported ACL reconstruction procedure.⁸ In Group U, the ACL was completely resected from its femoral and tibial attachments using a sharp scalpel (Fig 1, A and B), and a 2-mm guidewire was inserted into the tibia at the center of the ACL attachment.

A tibial tunnel was created using a 10-mm cannulated drill, using the wire as a guide. To create a femoral tunnel, a guidewire was inserted at the center of the femoral ACL attachment toward the lateral femoral condyle. Then, a 4.5-mm cannulated drill was inserted over the guidewire. After measurement of femoral tunnel length, the distal end of the tunnel was gradually enlarged using 10-mm reamers (Fig 2, A and B). Therefore, a 20-mm long socket was made for tendon graft placement. A 10-mm MMRL was created based on the methods used in previous studies.^{2,3,9} The interface between the posterior horn of the medial meniscus and the posterior capsule was incised, beginning adjacent to the course of the posterior cruciate ligament and continuing 10-mm medially (Fig 3A).

The vertical orientation of the scalpel was maintained and continued inferiorly to the tibial plateau

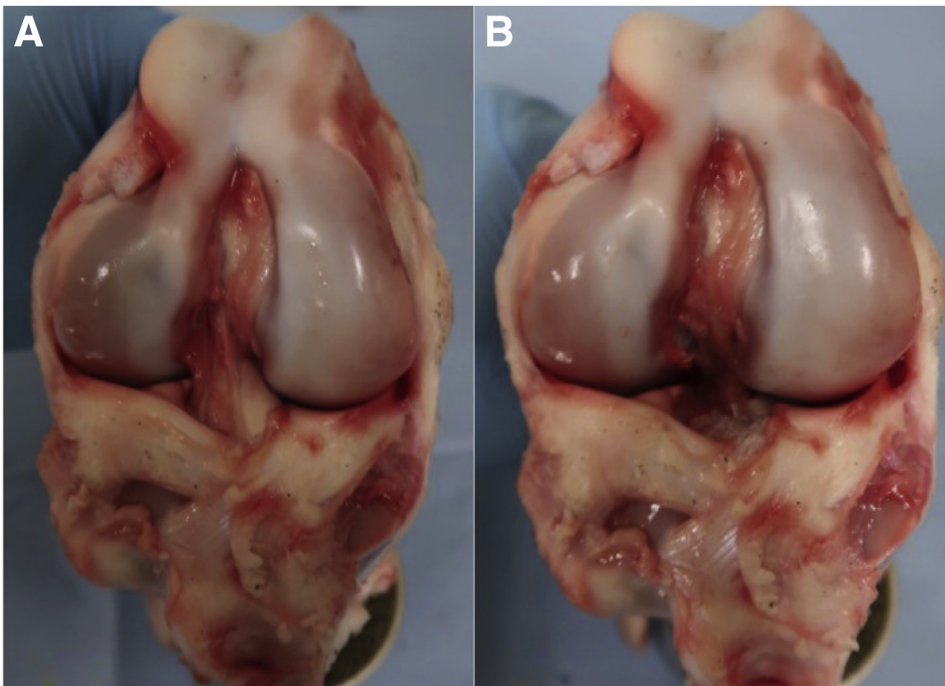
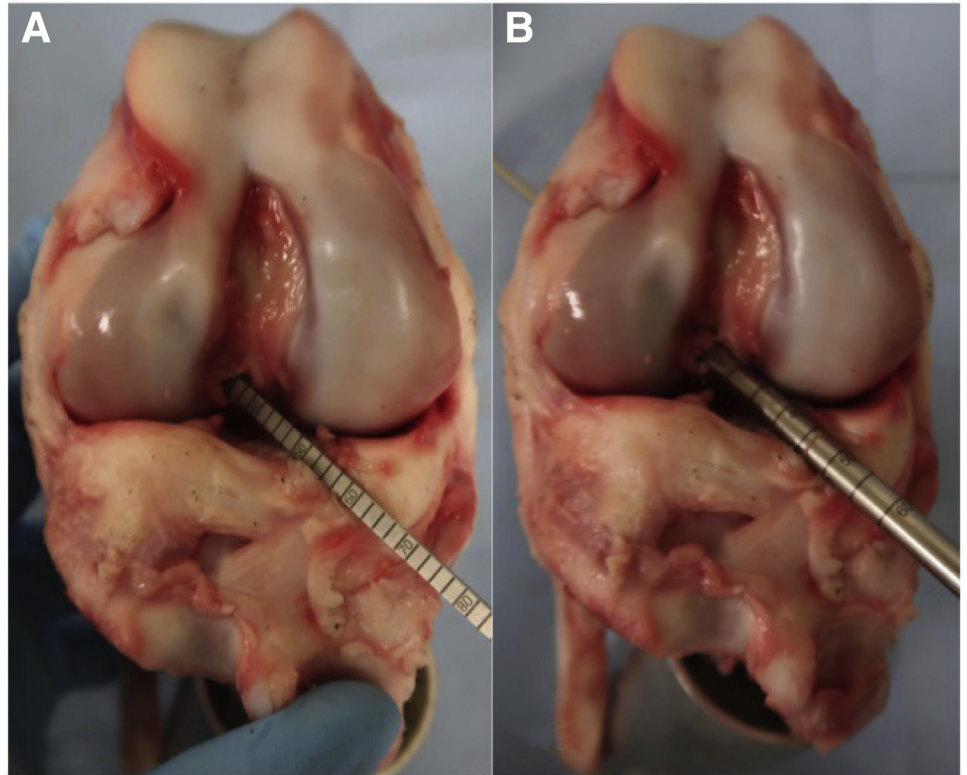


Fig 1. (A) Porcine knee potted into the aluminum tubes. (B) The anterior cruciate ligament was completely resected from its femoral and tibial attachments using a sharp scalpel.

Fig 2. (A) Measurement of femoral tunnel length using depth gauge. (B) The distal end of the tunnel was enlarged using 10-mm reamers.



throughout the incision of the junction of the posterior horn of the medial meniscus and the posterior capsule, creating a ramp lesion spanning the entire meniscocapsular junction,⁹ before introduction of the graft into the tibial bone tunnel. The patellar tendon of the ipsilateral knee was used for the graft composite. The length and diameter of the graft were approximately 50

mm and 10 mm, respectively. Two Size 3 ETHIBOND sutures (Smith & Nephew Endoscopy, Andover, MA) were attached at the proximal and distal ends of the tendon grafts in a whipstitch fashion (Fig 4).

The sutures attached to the graft were introduced from the tibial tunnel into the joint cavity and pulled out through the femoral tunnel to the outside of the

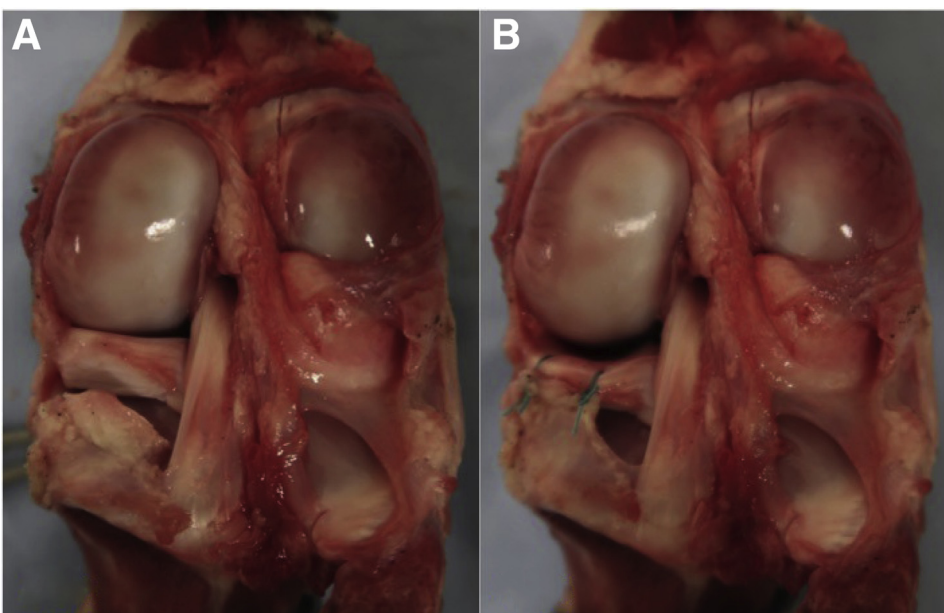


Fig 3. (A) Meniscal ramp lesion. (B) Meniscal ramp lesion repair using an ULTRABRAID size 2.



Fig 4. Two size 3 ETHIBOND sutures were attached at the proximal and distal ends of the tendon grafts in a whipstitch fashion.

lateral condyle. By pulling the femoral end of this suture, the tendon graft was introduced into the joint cavity through the tibial tunnel and then placed in the femoral socket. After the femoral side of the graft was tethered by attaching the ENDOBUTTON (Smith & Nephew Endoscopy) to the femoral cortex, an initial tension of 20 N was applied to the distal sutures by pulling the double-spike plate. Then, the plate was fixed onto the tibia with a cancellous bone screw at 60° of knee flexion, according to previous studies.⁸ The graft was introduced and fixed without MMRL repair.

In Group R, the ACL resection, graft preparation, and MMRL creation were performed as for Group U. MMRL repair was performed before the introduction of the graft, using the all-inside technique described by

Hatayama et al.¹⁰ First, Size 2 nylon was loaded into an ACCU-PASS suture shuttle (Smith & Nephew Endoscopy); the tip of the hook penetrated the central fragment of the medial meniscal tissue, followed by the meniscal peripheral rim tissue and the meniscocapsular structure. Then, the nylon was switched to an ULTRABRAID size 2 suture (Smith & Nephew Endoscopy) and a sliding knot suture was applied to the posterior part of the meniscus. This maneuver was repeated twice (Fig 3B). Following the meniscal ramp lesion repair, the graft was introduced and fixed as with Group U.

Biomechanical Testing of the Femur–ACL–Tibia (FAT) Complex

The knee reconstructions were kept moist with saline spray throughout the procedure. The prepared FAT complex specimens were mounted on a tensile tester (Tensilon RTG 1250; Orientec, Tokyo, Japan) with a set of specially designed grips. This measurement system was the same as that used in previous biomechanical studies using large animals.^{6–8} The tibia was flexed at 90° against the femur.⁹ Before testing, the specimen was preconditioned with a static preload of 5 N for 30 seconds,¹¹ followed by 2,000 cycles of loading between 0 and 100 N with a cross-head speed of 100 mm/min, to simulate the tibial anterior drawer setting (Fig 5A).⁷

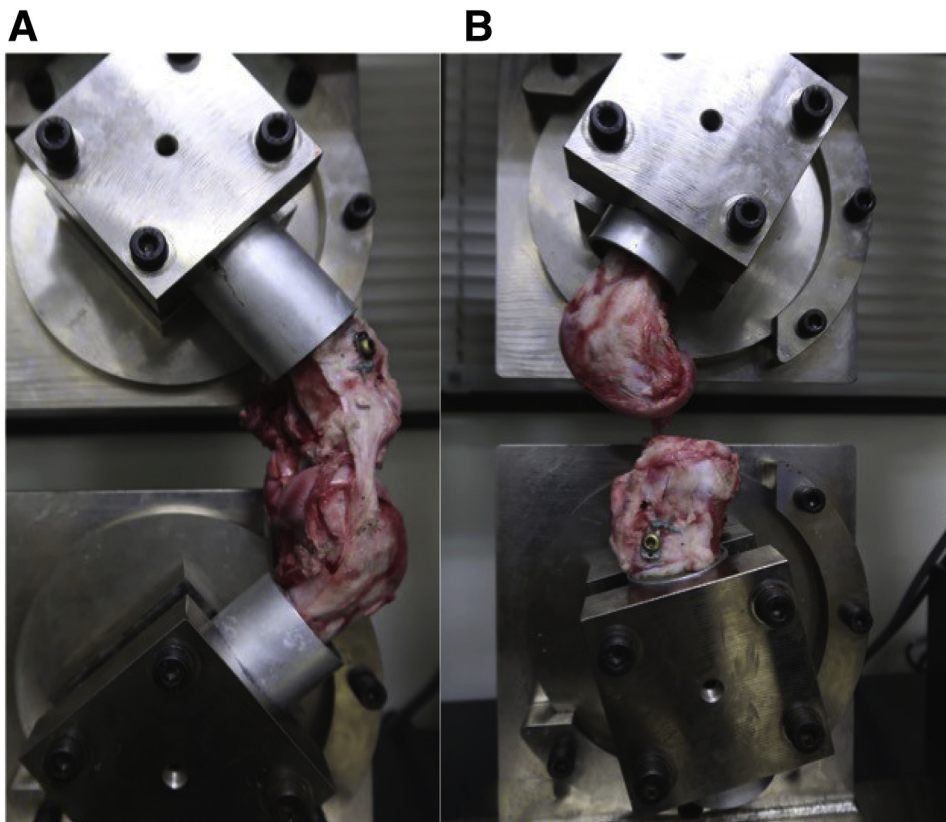


Fig 5. Femur–graft–tibia complex specimen mounted on a tensile tester with a set of specially designed grips. (A) Cyclic loading to simulate the tibial anterior drawer setting was applied with 90° of knee flexion. (B) A tensile load was applied to the anterior cruciate ligament parallel to its long axis.

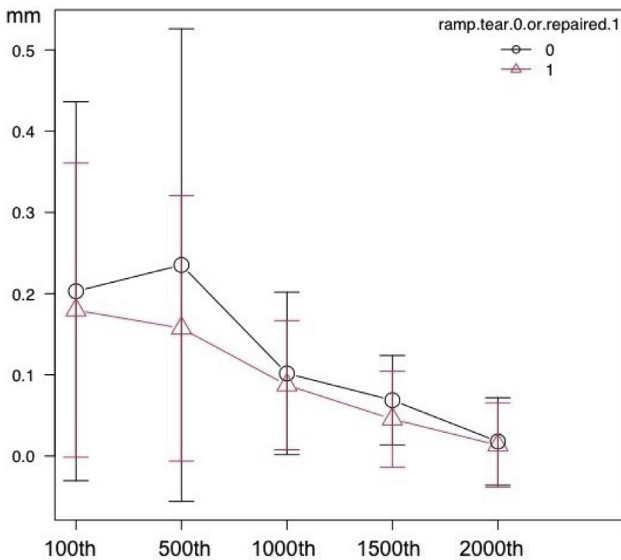


Fig 6. Result of length changes.

The increase in construction length was recorded. Length changes were reported from the first to 100th, 100th to 500th, 500th to 1,000th, 1,000th to 1,500th, and 1,500th to 2,000th cycles.¹¹ Anterior translations at the 100th, 500th, 1,000th, 1,500th, and 2,000th cycles were also recorded. The increase in construction length and anterior translations were measured using specific software (Tensilon Advanced Controller for Testing; Orientec). Then, connective ligaments, menisci, and the capsule around the knee joint (except for the reconstructed ACL) were removed. Each specimen was stretched to failure, with preconditioning at a cross-head speed of 50 mm/min. A tensile load was applied to the ACL parallelly along its long axis (Fig 5B). These conditions have frequently been used for measurement in previous studies with large animal models.^{6-8,12-14}

Failure modes were recorded. A load–elongation curve was created using same software. The structural properties—upper yield load, maximum load, linear stiffness, and elongation at failure—of the FAT complex were determined via software calculations.

Statistical Analysis

All data from statistical analyses are presented as mean ± standard deviation. A priori power analysis was conducted based on that increased translation of 3 mm is clinically significant. It was determined that ACL reconstruction with unaddressed MMRL (Group U; n = 10) and ACL reconstruction with repaired MMRL (Group R; n = 12) would provide a power of 91.5% to detect a difference ($\alpha < 0.05$) in the mean anterior translation. Repeated measures analysis of variance was used to evaluate differences in length changes and anterior translations during cyclic loading. The Student *t* test was used to evaluate the differences in structural properties between the groups. Fisher exact test was

used to evaluate the differences in failure modes between the groups. All statistical analyses were performed using EZR software (R Foundation for Statistical Computing, Vienna, Austria).¹⁵ *P* values <.05 were considered statistically significant.

Results

Displacement During Cyclic Loading

Length Changes

There were no significant differences in length changes for the first to 100th (0.20 ± 0.23 mm in Group U, 0.18 ± 0.18 mm in Group R), 100th to 500th (0.24 ± 0.29 mm in Group U, 0.16 ± 0.16 mm in Group R), 500th to 1,000th (0.10 ± 0.10 mm in Group U, 0.09 ± 0.08 mm in Group R), 1,000th to 1,500th (0.07 ± 0.06 mm in Group U, 0.05 ± 0.06 mm in Group R), and 1,500th to 2,000th cycles (0.02 ± 0.05 mm in Group U, 0.01 ± 0.05 mm in Group R) (Fig 6).

Anterior Translation

There were no significant differences in anterior translations at the 100th (1.9 ± 1.5 mm in Group U, 2.3 ± 2.3 mm in Group R), 500th (2.1 ± 1.7 mm in Group U, 2.5 ± 2.3 mm in Group R), 1,000th (2.2 ± 1.8 mm in Group U, 2.6 ± 2.3 mm in Group R), 1,500th (2.3 ± 1.9 mm in Group U, 2.6 ± 2.3 mm in Group R), and 2,000th cycles (2.3 ± 1.9 mm in Group U, 2.6 ± 2.3 mm in Group R) (Fig 7).

Biomechanical Evaluations of the FAT Complex

There were no significant differences in upper yield load (82.4 ± 31.2 N in Group U, 90.0 ± 38.5 N in Group R, *P* = .62), maximum load (109.9 ± 28.6 N in Group U, 124.0 ± 56.4 N in Group R, *P* = .48), linear stiffness (12.1 ± 4.7 N/mm in Group U, 12.5 ± 4.3 N/mm in

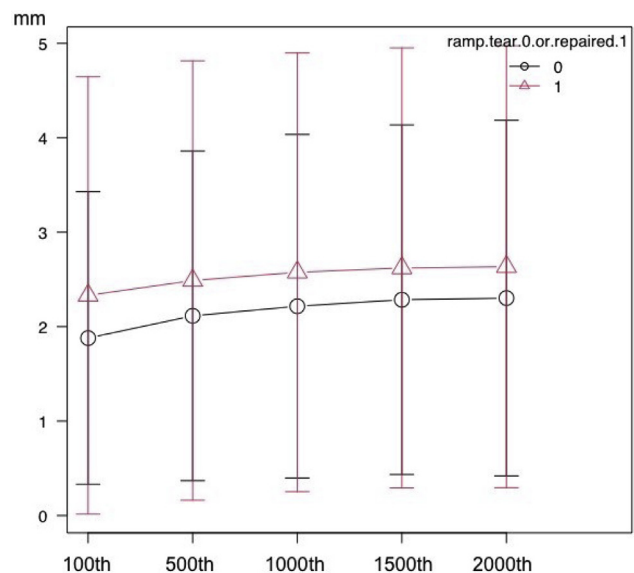


Fig 7. Result of anterior translations.

Table 1. Results of Tensile Testing

Parameters	Group U (n = 10)	Group R (n = 12)	P Value
Upper yield load, N	82.4 (31.2)	90.0 (38.5)	.62
Maximum load, N	109.9 (28.6)	124.0 (56.4)	.48
Linear stiffness, N/mm	12.1 (4.7)	12.5 (4.3)	.84
Elongation at failure, mm	13.5 (7.3)	16.6 (7.5)	.30

NOTE. Data are expressed as mean (standard deviation).

Group R, $P = .84$), or elongation at failure (13.5 ± 7.3 mm in Group U, 16.6 ± 7.5 mm in Group R, $P = .30$) (Table 1).

Observation of Failure Mode at the Time of Tensile Testing

All specimens in Group U and Group R failed through midsubstance rupture of the graft.

Discussion

Simultaneous MMRL repair at the time of ACL reconstruction, in our model, did not significantly influence length changes and anterior translations during cyclic loading, or postoperative structural properties and failure modes. Even though unaddressed MMRL potentially increases forces on the ACL graft, ultimately leading to failure,^{3,16,17} simultaneous MMRL repair did not show a significant effect for preventing graft elongation during cyclic loading or decreasing anterior laxity. A plausible reason for this is the time-zero nature of this study. DePhillipo et al.¹⁸ reported, in a human cadaveric study, that MMRL creation significantly increased anterior translation at 90° of knee flexion in the ACL-deficient condition. They described the ACL as the primary stabilizer for anterior translation and reported that when it is adequately reconstructed, changes in anterior translation after MMRL creation may not be significant,¹⁸ which is in accordance with our study. However, they performed static translation test and did not evaluate the change of anterior translation after cyclic loading. The medial meniscus is firmly attached to the posterior margin of the tibial plateau.¹⁹ and it acts as a secondary stabilizer for anterior translation and tibial rotation in the ACL-deficient knee. Therefore, it is possible in this study that the time-zero stability of ACL reconstruction was sufficient to not overload the medial meniscus as a secondary stabilizer. However, we did not evaluate the effect on rotational stability of MMRL repair performed simultaneously with ACL reconstruction. Although MMRL repair has been reported to restore the rotational stability at lower flexion angles, it failed to restore internal and external rotation at greater flexion angles.¹⁸ We are interested in clarifying this in the future, and a flexion–extension simulation model will be warranted for performing

experiments. Moreover, clinical trials of our surgical procedure are warranted to validate our conclusions.

Limitations

Our study has some limitations. First, a porcine model was used; therefore, some findings may not be directly transferrable to clinical practice in human patients. The differences between young human tibias and porcine tibias, regarding cancellous bone properties, may have influenced fixation strengths. However, porcine knees are reported to be similar to human knees in many respects.⁷ Second, the influence on flexion–extension motion and any biological healing responses could not be reported because this study only assessed the time-zero structural properties of the femur–graft–tibia complex with and without MMRL repair. Cyclic and tensile force involving only an isolated portion of the knee were tested *ex vivo*, which might not reflect the actual anterior forces that fixation constructs are subject to *in vivo*. Third, each surgery was fully performed in the open and did not replicate the arthroscopic environment. Fourth, only MMRL repair using the ACCU-PASS suture shuttle was evaluated. No consensus is available regarding the optimal ramp lesion repair technique,⁹ and we are interested to know whether the repair technique may influence results. Fifth, a limited number of specimens and implants were available for use, which lowered the available sample size in each group, and we had no control group of ACL-reconstructed porcine knees without any ramp lesion to see the efficacy of ACL reconstruction alone.

Conclusions

Simultaneous MMRL repair at the time of ACL reconstruction in this model did not decrease length changes and anterior translations during cyclic loading. In addition, simultaneous MMRL repair at the time of ACL reconstruction did not contribute to better structural properties during cyclic loading.

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