Biomechanical and Biological Findings Between Acute Anterior Cruciate Ligament Reconstruction With and Without an Augmented Remnant Repair: A Comparative in Vivo Animal Study

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Purpose: To investigate whether remnant-preserving anterior cruciate ligament reconstruction (ACLR) for acute complete anterior cruciate ligament (ACL) tears can improve the biomechanical strength, revascularization status, and proprioceptive recovery potential of the grafted tendons compared with conventional ACLR. **Methods:** An acute complete ACL femoral detachment model was created in 60 rabbits. The animals were randomly allocated into the remnant-repairing ACLR group (group 1, n = 30) or the conventional ACLR group (group 2, n = 30). The ACL remnants were either acutely repaired with a femoral tensioning technique in group 1 or completely debrided in group 2. For group 1, remnant structural integrity was evaluated macroscopically and divided into grade A (bridging femur and tibia) and grade B (not bridging femur and tibia). Then, the remnant-to-graft healing capacity was assessed histologically. For intergroup comparisons, the biomechanical strength of the grafted tendons was evaluated by tensile tests and the revascularization status (vascular endothelial growth factor) and proprioceptive recovery potential (neurofilament) of the grafted tendons were evaluated by immunofluorescent staining. All assessments were performed postoperatively at week 24. **Results:** In group 1, 60% of remnants (18 of 30) showed grade A and 40% (12 of 30) showed grade B structural integrity. An obvious remnant-to-graft interval could be detected through the whole length of the graft. Tensile tests showed that the ultimate failure loads of the grafted tendons were similar between the groups ($P = .365$). In addition, there were no significant differences in the number of vascular endothelial growth factor–positive vessels and neurofilament-positive mechanoreceptors at either the femoral ($P = .887$ and $P = .578$, respectively), midsubstance ($P = .063$ and $P = .546$, respectively), or tibial ($P = .193$ and $P = .978$, respectively) level within the grafted tendons between the groups. **Conclusions:** The acute remnant-repairing ACLR in our rabbit femoral ACL detachment model showed no biomechanical and biological advantages compared with conventional ACLR. The acutely repaired ACL remnants presented a high proportion of poor structural integrity and low remnant-to-graft healing capacity. **Clinical Relevance:** During our clinical practice, conventional ACLR may still not be replaced by remnant-repairing ACLR for the treatment of acute complete ACL tears.

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Although anterior cruciate ligament reconstruction (ACLR) has become a common orthopaedic surgical procedure over the past several decades, the optimal method for ACLR remains controversial.[1-5] Recent studies have emphasized that a successful ACLR may depend not only on the biomechanical stability but also on the biological healing outcomes of the grafted tendon.[5-10]

In complete anterior cruciate ligament (ACL) tears, especially in the acute setting, there are often thick and abundant ACL remnants observed during arthroscopic examination.[11,12] Moreover, the accumulation of histologic studies concerning ACL remnants enabled us to consider a remnant-preserving ACLR as another treatment option for acute complete ACL tears.[13-16] The remaining vascular and neural elements within the preserved ACL remnants may potentially be a source of revascularization and improve the proprioceptive recovery potential, as well as the biomechanical stability, of knee joints.[10,13-15] Indeed, some studies have shown

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that remnant-preserving ACLR produced good clinical outcomes.[17-28]

Techniques for remnant-preserving ACLR may vary according to the patterns of the ACL injury.[5] For an acute complete ACL tear, in which a tibia-based ACL remnant is usually encountered, remnant-preserving ACLR with an augmented remnant repair could be performed.[11] In addition, some studies concluded that the ACL remnants were more reasonable to be preserved in the acute setting, beyond which the vascular and neural elements within the remnants would degenerate rapidly over time.[13-15,29] Although there is increasing clinical evidence supporting remnant-preserving ACLR,[17,18,22,24,25,30] the proposed beneficial effects, such as improved revascularization status, proprioceptive recovery potential, and biomechanical strength of the grafted tendon, have yet to be examined experimentally.

Therefore an acute complete femoral ACL detachment animal model was created, aiming to investigate whether remnant-preserving ACLR for acute complete ACL tears can improve the biomechanical strength, revascularization status, and proprioceptive recovery potential of the grafted tendons compared with conventional ACLR. We hypothesized that for acute remnant-repairing ACLR, the biomechanical strength, revascularization status, and proprioceptive recovery potential of the grafted tendons would be better than those for conventional ACLR.

Methods

Study Design

Sixty adult, female New Zealand white rabbits[8] weighing 3.0 to 4.0 kg were used in this study. Our study received permission from the institutional animal care and use committee of our hospital. The rabbits were randomly allocated into 2 groups (30 rabbits in each group) according to random numbers generated by a computer. An acute complete femoral ACL detachment model was created in each animal. Meanwhile, an index unilateral single-strand ACLR was performed immediately. Group 1 (n = 30) was treated by remnant-repairing ACLR, and group 2 (n = 30) was treated by conventional ACLR. Semitendinosus tendon autografts were used for all operations. The operative side was determined randomly by choosing a sealed envelope containing the operative side (right or left) for each animal before the procedures.

Preparation of Acute Complete Femoral ACL Detachment Model

In this study an acute complete femoral ACL detachment model was created in each animal.[10] First, all animals were anesthetized with ketamine (35 mg/kg) and xylazine (5 mg/kg). Then, the operative side was shaved, scrubbed with povidone-iodine, and aseptically draped; a 5- to 6-cm-long medial parapatellar longitudinal incision was made; and the patella was laterally subluxated until the normal ACL was clearly exposed. Finally, the ACL remnant was obtained by transecting the normal ACL from its femoral insertion site, whereas the remainder, including the midsubstance and the tibial insertion site, was kept intact.

Surgical Techniques

A single-strand semitendinosus tendon autograft was harvested from the operative side and prepared with weaving sutures on both ends by use of 2 No. 4-0 Ethibond sutures (Ethicon, Somerville, NY). The length and cross-sectional diameter (measured at the midpoint of the entire length of the autografts) of the ACL autografts were measured 3 times for each animal with a Vernier caliper with 0.1-mm resolution. The mean values were then recorded. All operations and measurements were performed by the same surgeon (G-y.S.). Both the remnant-repairing ACLR and the conventional ACLR were performed immediately after the acute complete femoral ACL detachment models were created.

For remnant-repairing ACLR, 3 to 4 simple sutures were applied to the femoral end of the remnant to provide a traction force using 1 No. 4-0 absorbable suture. A 2.0-mm Kirschner wire was used as a reamer to drill the tibial and femoral tunnels. The center of the tibial tunnel was selected approximately 1 mm posterior to the center of the native tibial insertion site. To protect the remnant, we retracted the sutures attached to the remnant anteriorly while drilling the tibial tunnel. The femoral tunnel was drilled at the center of the femoral footprint. After tunnel preparation, we performed the ACLR with an augmented ACL remnant repair by pulling the leading sutures of the graft and the traction sutures of the remnant simultaneously into the femoral tunnel. We fixed the graft and the remnant with 1 EndoButton (Smith & Nephew Endoscopy, Andover, MA), ensuring that the proximal end of the remnant reached the entrance of the femoral tunnel. After tibial fixation with 1 EndoButton, another wrapped suture, which was placed circumferentially around the graft and remnant, was placed near the entrance of the femoral tunnel using 1 No. 4-0 absorbable suture (Fig 1).

For conventional ACLR, the ACL remnant was completely removed. Both the tibial and femoral tunnels were made at the center of the ACL footprints. The ACL grafts were fixed with an EndoButton on both sides in the same manner described earlier.

Rationale for Surgical Techniques

A pilot study was first designed to test the rationale for the surgical techniques. Eight rabbits were equally divided into the remnant-repairing ACLR group (n = 4)