Differential Pretensions of a Flexor Tendon Graft for Anterior Cruciate Ligament Reconstruction: A Biomechanical Comparison in a Porcine Knee Model

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Purpose: The best way to apply the pretension force to the soft tissue graft during anterior cruciate ligament (ACL) reconstruction remains controversial. We compared manual, intra-, and extra-articular pretension techniques and determined the magnitude of displacement of the femur-graft-tibia complex in response to repetitive loading. **Type of Study:** A biomechanical-controlled study. **Methods:** Fresh porcine knees and profundus digital flexor tendons of hind limbs were used. Specimens were divided into 3 groups. Group A (manual pretension, n = 9) consisted of grafts that were pretensioned only by a maximal manual pull before final fixation on the tibial side. Group B (extra-articular pretension, n = 9) consisted of grafts that were pretensioned using a commercial tensiometer at 89 N for 15 minutes on the tendon preparation board, followed by pulling using maximal manual force before final fixation. Group C (intra-articular pretension, n = 9) consisted of grafts that were fastened on the femoral side first and then underwent application of a pretension force at 89 N for 5 minutes before final fixation on the tibial side. These femur-graft-tibia complexes from the 3 groups were loaded from 0 to 150 N at a frequency of 1 Hz for 1,000 cycles and then underwent a tensile load-to-failure test at a rate of 150 mm/min. **Results:** The displacement of the femur-graft-tibial complex in response to cyclic loading for group C (5.4 ± 0.3 mm) was significantly lower than those for groups A (12.5 ± 1.1 mm) and B (8.8 ± 0.8 mm) ($P < .001$). The fixation stiffness of group C (47.9 ± 17.6 N/mm) was significantly greater than that of group A (32.5 ± 9.7 N/mm) ($P < .05$) but not significantly different from that of group B (53.1 ± 9.1 N/mm). The ultimate failure load in each group was not significantly different. **Conclusion:** Intra-articular pretension of the graft before final fixation can significantly minimize graft elongation at time 0 compared with manual and extra-articular pretension. **Clinical Relevance:** Intra-articular or in vivo pretension of the graft using instruments may minimize the graft elongation in the early period of rehabilitation after ACL reconstruction. **Key Words:** Pretension—ACL reconstruction—Tendon graft.

Anterior cruciate ligament (ACL) rupture is a common sports injury of the knee. Endoscopic ACL reconstruction with either bone-patellar tendon-bone graft or a hamstring tendon graft is the standard procedure for this injury. However, which graft is better for ACL reconstruction remains controversial. Disadvantages of the bone-patellar tendon-bone graft include patellofemoral pain, weakness of the quadriceps muscle, possible rupture of patellar tendon, arthrofibrosis of the knee, and patellar fracture.[1,2] As a result of these disadvantages, using a hamstring tendon graft to replace a torn ACL has gained popularity in recent years. However, disadvantages of the hamstring tendon graft include potential hamstring tendon muscle weakness, higher failure rate, and a higher rate of hardware removal compared with the patellar tendon autograft.[2] Another major concern with hamstring

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tendon grafts is their fixation and their time-dependent viscoelastic behavior.[3,4]

Initial graft tension is an important factor that influences the clinical outcomes of ACL reconstruction.[3,5,6] The hamstring tendon is a viscoelastic material, which means if the tendon sustains a constant tensile load, the tendon will increase in length with time.[3,4] Studies on mechanical properties of viscoelastic materials have suggested that substantial elongation (creep) could occur in response to a constant load or repetitive cyclic loads. The viscoelastic properties of the tendon graft under sustained tensile loading may result in loss of graft tension over time because of elongation of the graft, which may elicit failure of ACL reconstruction during early postoperative time before tendon-to-bone incorporation.[7-9] Pretension of the viscoelastic graft before fixation could decrease the amount of elongation. Most surgeons agree that it is necessary to apply some initial graft tension before the graft is securely fixed.[10,11] However, the effects of pretensioning are also time and load dependent, so the interval between load and unload must also be controlled. The effect of pretension could decrease if the unload period of a pretensioned graft is too long. O'Brien et al.[12] found significant drops in human patellar tendon graft tension after a 15-minute unload period; in contrast, Graf et al.[13] found that the effect of preconditioning on the primate patellar tendons was still significant after 30 minutes of unloading.

The pretension techniques used in clinical practice also influence its effects. Using manual pull of the graft by surgeons before final fixation provided an inconsistent tension, with surgeons only able to apply limited extent of the maximal tension to the graft.[10] How to apply more accurate and consistent tension to the graft during surgery has not been well addressed. The purpose of this study was to compare 3 different graft pretension techniques including manual, extra-articular, and intra-articular methods by evaluating the magnitude of displacement and mechanical properties of porcine femur-graft-tibia complex by using a biomechanical cyclic loading followed by a load-to-failure test. We further hypothesized that the constructs properties such as graft elongation and stiffness would be influenced by the different pretension techniques because we expected intra-articular pretension of the graft using the tensiometer would have a significantly less graft elongation after cyclic loading test than that of other pretension techniques.

METHODS

Thirty-six porcine stifle knee joints were harvested from 1-year-old fully mature Landrace-Yorkshire-Durou pigs weighing about 120 kg each. The ends of the femur and tibia were freed of soft tissues before they were put in a cylindrical tube and fixed with plaster of Paris (Chung Fan Gypsum Co., Taipei, Taiwan). Twenty-seven fresh profundus flexor digital tendons from porcine hind limbs were selected for ACL tendon grafts. The bifurcated tendon was divided into 2 halves carefully along the fiber orientation. The size of each graft averaged 160 mm in length and 4 mm in diameter. A single porcine tendon graft was folded to a doubled tendon and prepared for construction; the length of the folded graft was 80 mm before implantation. Then no. 5 Ethibond sutures (Ethicon, Somerville, NJ) were whipstitched to the 2 free-tendon ends. The tunnels of the tibia and femur were drilled by a 9-mm coring reamer at the native ACL insertion area. The tubelike cancellous bone was removed from the reamer for bone mineral density (BMD) measurement. The BMD was measured by Archimedes' principle. Both a cup filled with distilled water and a specially designed holder were put together on a digital balance (Sartorius, BP310S, Goettingen, Germany) and then calibrated to zero before measurement. The bone plug was put within the holder in air first; the weight of the bone plug could be measured. Then the holder with bone plug was sunk into the distilled water; the weight of the bone plug was again measured and net change in weight recorded. The net weight presented as the volume of the bone plug, then the BMD of the bone plug could be calculated.

The graft was looped proximally around a cross-pin (3-mm in diameter) in the femoral tunnel; then the graft was pulled through the tibial tunnel and securely fixed with a 9 × 35 mm Titanium interference screw (RCI; Smith-Nephew, Andover, MA), and the sutures were attached to a screw post with a washer. The grafts were divided into the following 3 pretension groups (Fig 1): group A (manual pretension, n = 9) consisted of grafts that were pretensioned only by a maximal manual pull by the first author before final fixation on the tibial side (Fig 2). The manual force recorded from the test machine ranged from 45 to 65 N. The duration of the manual tension was ranged from 30 to 50 seconds. Group B (extra-articular pretension, n = 9) consisted of grafts that were pretensioned using a commercial tensiometer (GraftMaster; Smith-Nephew, MA) at 89 N (20 lb) for 15 minutes on