The Most Important Fibers In The Femoral Attachment Of The Anterior Cruciate Ligament For Resisting Tibial Displacements

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Introduction: The ideal outcome for an anterior cruciate ligament (ACL) reconstruction is to restore the native knee function, both the stability and kinematics. During ACL reconstruction the exact position of the femoral attachment of the graft is most important. Recent anatomical studies have shown that the femoral attachment of the native ACL is composed of a dense, direct attachment of the ACL mid-substance fibers, and thin, ‘fan-like extension’ areas where the fibers spread out anteriorly and posteriorly [1-4]. However, no biomechanical study has been conducted to clarify the roles of the fibers of the ACL in relation to the femoral attachment including both mid-substance and fan-like extension fibers. It is critical to perform such a study because it will strongly affect the femoral tunnel creation in ACL reconstruction procedures. The purpose of this study was to clarify the load-bearing functions of the above-described fibers of the femoral ACL attachment in resisting tibial anterior drawer and rotation. It was hypothesized that resection of the fan-like attachment fibers would not have a significant effect and, therefore, that most of the load transmitted by the ACL would be in the central relatively narrow area, to which the dense mid-substance fibers of the ACL directly insert.

Methods: Eight fresh-frozen cadaveric right knees were used. After the tibia and femur shaft were exposed leaving the knee ligaments intact, they were placed in cylindrical steel pots and fixed. The medial femoral condyle was separated using a reciprocating saw according to our previous study [6]. The femoral attachment of the ACL was divided into the mid-substance area that had dense fibers inserting directly into the femur and anterior and posterior fan-like extension areas (Fig 1). Four lines were drawn parallel to the long axis of the mid-substance fiber attachment. Five more parallel lines were then drawn parallel to Blumensaat’s line. This method divided the femoral attachment of the ACL into twelve partitions, A (most posterior) to L (most anterior). The separated femoral condyle was anatomically relocated using threaded steel rods. The anterior-posterior (A-P) laxity and internal-external rotation laxity were measured using a robotic knee joint biomechanical testing system. A knee joint biomechanical testing system consisting of a 6 degree-of-freedom industrial robotic manipulator (TX90, Stäubli Ltd), robot controller, 6 axis force/torque sensor, end effector attachment for tibial bone pot, and a fixed femoral mounting on the base of the robot was developed (Fig 2). Each of the following translations and rotations were applied to the tibia at full extension, 30, 60 and 90 degrees of knee flexion: 6 mm anterior-posterior translation, 10 degrees internal-external rotation at full knee extension.
and 15 degrees internal-external rotation at 30, 60, and 90 degrees of knee flexion. After the intact knee was tested using this protocol, the partial cutting of the ACL at the femoral attachment was performed from a posterior approach at full knee extension. The cutting order was AB→CD→E→F→G→H→IJ→KL. Namely, the ACL fibers were cut sequentially from the bone: the posterior fan-like extension area in 2 stages, the mid-substance area in 4 stages, and then the anterior fan-like extension area in 2 stages. Each robotic biomechanical test was performed under each situation. The biomechanical data were analyzed by using the one-way ANOVA with the Tukey-Kramer post-hoc test. The significance level was set at P<0.05.

**Results:** Concerning the anterior translation, the percentage of the force released by each of the sequential cuts was calculated at each angle of knee flexion based on the measured forces (Fig 3), when the force of the intact ACL was considered 100%. There was no significant difference between the intact knee and the partial ACL-deficient knee after cutting the posterior fan-like extension fibers attachment areas AB and CD at any angle of knee flexion. At full extension, the percentage force showed a significant decrease after cutting E compared to the intact knee (P˂0.05). There was a significant decrease (P˂0.05) of the force after cutting G at 30 degrees of knee flexion, and after cutting H at 60 and 90 degrees of knee flexion. In order to analyze the load-bearing function of the fibers attaching to each part of the femoral ACL attachment from the clinical viewpoint, the force of the ACL in the intact knee condition was considered 100% and the percentage contributions were calculated after cutting each partition (Fig 5). Specifically, we calculated the percentage contributions of areas E+F and G+H, because they approximately showed the contributions of the posterolateral (PL) and anteromedial (AM) bundle attachments, respectively. The percentage contribution of the G+H area was dramatically greater than that of the E+F areas at each angle of knee flexion. The anterior fan-like extension fibers attachment area contributed very little (2-3%) to resisting tibial anterior drawer at any angle of knee flexion. The posterior fan-like extension fibers attachment area contributed 15±6% of the resistance to tibial anterior drawer at 0 degrees knee flexion, falling to 11±6% at 90 degrees. Concerning to the torque to produce 10 or 15 degrees tibial internal-external rotation, There was no significant difference of torque between the intact knee and the partial ACL-deficient knee after cutting AB, CD, E and F at full extension under a 10 degree internal rotation (Fig 4), although there was a significant decrease of the torque after cutting G (P<0.05). Cutting the ACL did not affect the torque to produce a 10 or 15 degrees tibial external rotation significantly.

**Discussion:** This is the first study on biomechanics of the mid-substance and fan-like extension fibers of the ACL femoral attachment. This study demonstrated that in the wide ACL attachment, 66 to 84% of the resistance to tibial anterior drawer force arose from the fibers of the ACL which attached to the mid-substance area of the femoral attachment close to the roof of the intercondylar notch, and the fan-like extension fibers contributed very little. In ACL reconstruction, the graft should be placed at the proximal mid-substance area in order to be sited at the ‘center of effort’ of the ACL. Concerning double-bundle reconstruction, the present study implied that the two femoral tunnels can be created in the proximal and distal mid-substance area.

**Significance:** This study has clarified the load-bearing functions of the fibers of the femoral ACL attachment in resisting tibial anterior drawer and rotation.
**Fig 1.** The partition of the femoral ACL attachment

**Fig 2.** The biomechanical testing system (TX90, Stäubli Ltd)

**Fig 3.** The percentage of the force released by each of the sequential cuts in response to 6 mm tibial anterior translation (*P < .05 compared with intact)

**Fig 4.** The percentage of the torque compared with the intact knee in response to internal rotation (*P < .05 compared with intact)

**Fig 5.** The percentage contribution of each area to a 6-mm anterior translation of the tibia as 100% in the intact knee condition (*P < .05 compared with others, #P < .05 compared with EF)

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