Effect of Fixation Angle and Graft Tension in Double-Bundle Anterior Cruciate Ligament Reconstruction on Knee Biomechanics in Human Cadaver

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Disclosures:

Introduction:
Anatomical observation has shown that the anterior cruciate ligament (ACL) consists of two bundles, the anteromedial (AM) bundle and posterolateral (PL) bundle. Some biomechanical studies have also found that double bundle (DB) ACL reconstruction was able to restore knee kinematics to that of the native ACL.1-3 However, in these studies, the fixation protocol varies widely and there is no consensus on the amount of graft tension applied and the knee flexion angle when the grafts are fixed. Miura et al reported the biomechanical comparison between two fixation protocols.2 Their protocol used the fixation angle of 30°/30° and 60°/0° for the AM/PL grafts. Based on the result of Miura, Vercillo et al indicated an excessive force on the PL bundle by using the former protocol and an excessive force on the AM bundle by using the later protocol.3 In their conclusion, when the PL graft is fixed at 15° of knee flexion, the AM graft should be fixed between 15° and 45°. However, a 3 tunnels procedure was used as the operation method for DB ACL reconstruction in their study. We modified the protocol of Miura and Vercillo to reduce the in-situ force (ISF) of the PL bundle using anatomical DB ACL reconstruction with a 4 tunnels procedure. The purpose of this study is to evaluate the effect of different combinations of knee flexion tibial fixation angle and graft tension in anatomical DB ACL reconstruction on graft ISF. The hypothesis of this study is that 45°/30N (for the AM bundle) and 15°/10N (for the PL bundle) will more closely restore the intact ACL in ISF.

Methods: Fourteen human cadaveric knees were tested using a robotic/universal force-moment sensor (UFS) system. Femur and tibia were cut approximately 20 cm from the joint line and secured within thick-walled aluminum cylinders with polyester resin (Bondo®, 3M, USA). The femur was rigidly mounted to the base of the robotic manipulator (CASPAR Stäubli RX90 robot, Orto MAQUET, Germany), and the tibia was fixed to the end-effector of the robotic manipulator (Model 4015, JR3 Inc,Woodland, Calif). Using the robotic/UFS testing system, the knee kinematics and the in-situ forces in the intact ACL and the ACL graft, as well as the in ISF in the AM and PL bundles and their respective replacement grafts, were obtained. As the sequence of tests was performed and the data acquired, 5 knee states were used: Intact state, ACL deficient state and four fixation protocols for the AM and PL bundle, respectively: (Recon 1) 30°/20N and 0°/20N, (Recon 2) 30°/30N and 0°/10N, (Recon 3) 45°/20N and 15°/20N, (Recon 4) 45°/30N, and 15°/10N. Two external loading conditions were tested in all states: (1) 89-N of anterior tibial load (ATL) at 0°, 15°, 30°, 60°, and 90° degrees of knee flexion and (2) combined rotational loads of 7-Nm of valgus torque and 5-Nm of internal tibial rotation torque at 0°, 15° and 30° of knee flexion for a simulated Pivot-Shift (SPS) Test. DB ACL reconstruction was performed via arthroscopy in an anatomic fashion using hamstring grafts. Both the AM and PL femoral tunnels were positioned using a Kirschner wire at the center of the insertion of each bundle of the ACL by visual inspection of the remnants of the transected bundles. Looped semitendinosus tendons and gracilis tendons, which were harvested from human cadavers, were used for the AM and the PL grafts, respectively. The diameter of the femoral tunnels for the AM and PL grafts was chosen according to the graft size (range, 7-8 mm for AM, and range, 5-6 mm for PL). For each graft, the femoral side was fixed using an EndoButton CL (Smith & Nephew, USA) and the tibial side was fixed using 2 spiked washers and 2 screws. Statistical analysis of the ATT and in-situ forces was performed using a 2-factor repeated measures analysis of variance (ANOVA) with knee state and knee angle as the factor, because all variables were measured on the same specimen. Because all tests were performed on the same specimen, multiple contrasts were performed. The two factors evaluated were the condition of the knee and the knee flexion angle. Statistical significance was set at P < .05.

Results: In response to ATL, the ATT for all the fixation protocols was not significantly different from the intact knee at the all knee flexion angle (P<0.05). (Figure 1) In terms of the AM bundle under ATL, the ISF of the AM bundle with Recon 3 at the 0° was significantly lower than that of the intact knee(P=.0135). The ISF of the AM bundle with each reconstruction at the 15° and 30° was significantly lower than that of the intact knee(P=.0028,.0105,.0001 and .0002 for 15° and P=.0011,.0028,.0001 and .0003 for 30°, respectively). In terms of the PL bundle under ATL, the ISF of the PL bundle with Recon 3 at the 0°, 15° and 30° was significantly higher than that of the intact knee(P=.0227,.0020 and .0031, respectively).(Figure 2) In terms of the AM bundle under SPS, the ISF of the AM bundle with each reconstruction at the all angle was significantly lower than the intact
knee. (P<0.05) In terms of the PL bundle under SPS, the ISF of the PL bundle with Recon 1 and Recon 2 at 0° was lower than that of the intact knee (P=.0215 and .0050, respectively) and the ISF of the PL bundle with Recon 3 at the 15° was higher than that of the intact knee (P=.0028). (Figure 3)

**Discussion:** This study showed that all of the tibial fixation protocols reproduced the kinematics of the intact knee during ATT in response to anterior tibial load. However, both 30°/0° fixation protocols had lower PL bundle force than the intact state. In addition, Recon 3 gave a higher ISF of the PL bundle than the intact state. The results of this study confirmed the hypothesis that 45°/30N (for the AM bundle) and 15°/10N (for the PL bundle) fixation will better restore the ISF of the bundles to that of the intact state. However, no reconstruction restored the force of AMB bundle to the intact state with ATL and SPS.

**Significance:** It is suggested that 45°/30N (for the AM bundle) and 15°/10N (for the PL bundle) fixation could be used for DB ACL reconstruction to mimic normal knee kinematics. However, these results showed that stabilizing the knee on ATT may indicate a potential risk of unbalance on the force sharing of the AM and the PL bundles.

**Acknowledgments:**

**References:**
Figure 2. In-Situ force under anterior tibial loading (89N)
* P<0.05
Figure 3. In-Situ force under simulated Pivot-Shift
* P<0.05