A robotic in vivo evaluation of loading characteristics of different anterior cruciate ligament reconstructions

INTRODUCTION:
Anterior laxity has been indicated as a causative factor in the development of osteoarthritis following anterior cruciate ligament reconstruction (ACLr). Increased laxity is associated with abnormal translation and/or rotation of the tibia with respect to the femur. With increased laxity comes greater and more abrupt joint motion, as well as less congruent contact between poorly fitting joint surfaces. These mechanisms may result in damage to the articular cartilage and/or menisci, which contribute to the progression of osteoarthritis (OA). On the contrary, other studies have suggested that over-constraining the joint by using too stiff of a graft during ACLr may also lead to increased tibiofemoral and/or patellofemoral contact forces, thus creating a potential environment for the development of OA.

In order to better understand the function of the ACL and the various grafts and techniques that are available for ACLr, the mechanical properties and loading characteristics of native ACL and different reconstructions have been evaluated in the laboratory setting. However, to our knowledge, controlled in vivo evaluations of the loading characteristics have not yet been performed. The purpose of this clinical study was to determine if the loading characteristics differ between the native ACL, single-bundle bone-patellar tendon-bone autografts (SBT), double-bundle semitendinosus/gracilis autografts (DBST), and double-bundle semitendinosus/gracilis allografts (DBAllo) using a novel, non-invasive robotic testing system. We hypothesized that SBST reconstructions would be stiffer than the native ACL, the DBAllo reconstructions would be less stiff than the native ACL, and that the DBST reconstructions would be similar to the native ACL.

METHODS:
Twenty-five patients that had previously undergone unilateral ACLr (7 women, 18 men; age = 41.4±12.9 y, ht = 174.5±10.4 cm, mass = 86.3±18.9 kg) volunteered to participate in this IRB-approved protocol. Subjects were recruited from the patient populations of two, high-volume, experienced board-certified orthopedic surgeons. All SBST reconstructions were performed by a single surgeon, and all DBST and DBAllo were performed by a second surgeon.

After providing informed consent, subjects were positioned in the robotic knee test system (RKT) in 25° of knee flexion with electromagnetic sensors placed bilaterally on each subject’s proximal anterior tibias, patellae, and the anterior thighs. The system was adjusted to accommodate for each patient’s leg length and natural varus/valgus alignment, and a series of pads and straps were used to secure the thighs, ankles, and feet for testing. The RKT then bilaterally cycled the knees into anterior (ATT) and posterior translation (PTT) while controlling both the amount of force applied and the rate at which the force was applied. The RKT first moved into ATT at a velocity of 1 mm/sec until the desired force threshold was reached. The target AP force threshold took each subject’s height and weight into account, equaling 100 N in addition the force necessary to raise the mass of the low leg. The RKT then reversed direction until the threshold was reached in PTT. The knee was preconditioned by performing 3 complete AP cycles, and the preconditioning cycles were followed by 3 additional test cycles. Testing was performed by a single examiner, with all data collected at 40 Hz. Kinematic analyses were performed using a free-body approach, and were defined as the instantaneous position and orientation of the tibia with respect to the femurs in 6 degrees of freedom. The test trials were averaged and ATT at 100 N were recorded for both the ACLr and healthy contralateral knees. In order to describe the loading characteristics of the graft, the stress-strain curves were generated for the concentric ATT loading portion for both the ACLr and contralateral knees. The slope between 0 and 25 N was calculated to describe the compliance of the graft when in a neutral position, and the slope between 75 and 100 N was calculated to describe the endpoint stiffness. For both neutral compliance and endpoint stiffness, values were expressed as N/mm with lower values being associated with a “looser” graft and higher values being associated with a “tighter” graft.

Subjects were divided into three groups: SBST (n=10), double DBST (n=7), or DBAllo (n=8). Kruskal-Wallis nonparametric calculations were used to compare ATT, neutral compliance, and endpoint stiffness between the three groups and the native ACL. Spearman’s rho correlation coefficients were calculated to determine the relationship between the time between surgery and evaluation with the neutral compliance and endpoint stiffness. Analyses were performed with SPSS Statistics v17.0 with p = 0.05 being considered significant.

RESULTS:
Side-to-side differences in ATT were similar between the 3 reconstructions (SBST=0.64±0.08 mm, DBST=1.5±3.19 mm, DBAllo=3.27±2.38 mm, p=0.30). While not significant (p=0.29), the SBT was slightly stiffer than the native ACL in the first 25 N of loading (SBST=4.19±1.59 N/mm, Native ACL=3.85±1.15 N/mm) whereas the DBST was slightly looser (3.65±1.06 N/mm) and the DBAllo looser still (DBAllo=2.96±0.75 N/mm). Endpoint stiffness was significantly lower for the DBAllo (10.60±2.16 N/mm) than the Native ACL (14.73±4.70 N/mm, p = 0.05), but there were no other significant differences with the SBST (13.59±3.23 N/mm) or DBST (10.96±1.51 N/mm).

Side-to-side differences in endpoint stiffness were not related to the duration of follow-up for any of the reconstructions (SBST rho = -0.29, DBST (rho = -0.46, DBAllo rho = -0.36). Side-to-side differences in neutral compliance were also not related to follow-up duration for the SBST (rho=0.42) or DBAllo (rho=0.31); however, neutral compliance of the DBST was related to the duration of follow-up (rho=0.89, p=0.007).

DISCUSSION:
The purpose of this clinical study was to determine if loading characteristics differ between the native ACL, SBST, DBST, and DBAllo. Previous reports have suggested that either increasing or decreasing ACL forces during ACLr may influence the development of OA. The current results demonstrate that loading patterns of the DBAllo and SBST significantly differ, with the SBST being slightly stiffer than the native ACL and the DBAllo being slightly looser than the native ACL. Loading characteristics of the DBST did not differ from the native ACL, and DBST appear to become more like the native ACL as the graft matures.

SIGNIFICANCE:
This study is the first to quantify the in vivo AP loading characteristics of these ACLr techniques, and demonstrated that DBAllo grafts differ from the Native ACL. Longitudinal studies are necessary to determine if mimicking the loading characteristics of the native ACL provides a benefit in terms of the development of OA.

REFERENCES: