Patterns of Load Sharing Under Increasing Anterior Tibial Loads

INTRODUCTION:
Osteoarthritis (OA) following anterior cruciate ligament (ACL) reconstruction remains a concern, possibly due to persistent joint instability. Cadaveric studies have suggested that anatomic double-bundle rather than single-bundle reconstruction may result in superior joint stability. In turn, it is hoped that improved postoperative joint stability will result in a lower incidence of OA, but this link is as yet unproven. Testing the ability of double-bundle ACL reconstruction techniques to provide superior stability and less OA may be faster in sheep than humans, since ACL-deficient animal models are known to develop OA relatively quickly (1). However, knowledge of the normal ACL and more specifically the load sharing between the two bundles of the ovine ACL is currently limited. This relationship must be better understood in order to create anatomically accurate double-bundle ACL reconstructions in this model. We aimed to examine this load sharing relationship over a range of joint flexion angles in response to increasing anterior tibial loads. We hypothesized that load sharing varied in response to changes in both flexion angle and external load magnitude. We also aimed to examine if physical interaction occurred between the bundles and hypothesized that it did.

METHODS:
Six fresh frozen ovine stifle joints were used in this study. First, fracture plates were implanted onto the femur and tibia of each specimen. Then, an instrumented spatial linkage (ISL) was attached to these plates through surgical posts. A passive flexion-extension (PFE) motion was applied manually to each joint and recorded using the ISL. The joint was then mounted on a 6-degree-of-freedom parallel robot and all the tissues except ACL were removed. Then, a coordinate measuring machine was used to reference each end of the ISL with respect to the robot coordinate system. The recorded PFE motion was converted into the motion of femur relative to the tibia and reproduced using the robot-ISL system. The joint was then cyclically loaded to 200 N in the anterior-posterior (AP) direction at five flexion angles (30°-90°, with 15° increments) and the force-displacement data were recorded for the intact ACL. Then, bundle transaction surgery was performed in which the anteromedial bundle (AM) was dissected for three joints and the posterolateral bundle (PL) was cut away for the remaining three joints. The joints were again loaded to 200 N in the AP direction for 30 cycles, at five flexion angles, and the force-displacement data recorded. In 25 N increments between 50 N and 200 N, the corresponding displacement values were identified from the force-displacement data for the intact ACL and from these displacement values the load borne by the isolated bundle (post-dissection) was determined. The load shared by the isolated bundle was reported as a percentage of the intact ACL load. To assess possible physical interaction between the bundles, the mean percentage loads shared by AM and PL bundles were summed. Physical interaction was deduced to occur if this value was less than 100%.

RESULTS:
The mean load shared by the AM bundle increased from full extension (in the sheep: 30°) to 75° of flexion at all anterior tibial loading (ATL) levels; whereas, mean load shared by the PL bundle decreased between full extension and mid flexion (60°) and then increased (Fig. 1-2). A statistical interaction was identified between the ATL level and the bundle type (P = 0.004) indicating that the response to increasing ATL differed between the bundles. The load borne by the AM bundle did not change in response to increasing ATL at each flexion angle; however, for the PL bundle the load shared increased in response to increasing ATL at each flexion angle. The sum of the mean loads borne by the AM and PL bundles was lowest (under 100%) at 60° and in response to 50 N ATL. As ATL increased this sum value increased, meaning that physical interaction between the bundles reduces with increasing ATL.

DISCUSSION:
The patterns of load sharing obtained for ovine ACL bundles demonstrate striking similarities to human knees (2), implying that the ovine stifle is an ideal biomechanical model of human knee joint for studying ACL reconstructions. We identified that the load sharing relationship between the AM and PL bundles of the ovine ACL varies as a function of joint flexion angle in response to ATLs. The PL bundle bears its largest load at full extension and smallest load at mid flexion whereas the AM bundle bears its smallest load at full extension but its greatest load close to full flexion. Furthermore, the load borne by the PL bundle increases in response to increasing ATL at each flexion angle but does not change significantly in the AM bundle. Physical interaction between the bundles is greatest at mid flexion and in response to lower ATLs. Therefore we accept our hypotheses. Considerable variability, however, was present in the data. This can be partially due to the application of passive paths, as there is both inter- and intra-tester variability for manually applied joint motions. Future work should investigate this load sharing relationship using in vivo joint paths. With these data it will be possible to begin the design of double-bundle reconstruction techniques in this species with functional properties similar to the native structure. In turn, in vivo experiments can then test whether anatomic double-bundle reconstructions are superior to single bundle techniques in the prevention of premature OA.

SIGNIFICANCE:
Understanding the load sharing and physical interaction between ovine ACL bundles in response to changes in joint flexion angle and external load magnitude is instrumental to optimize double-bundle graft tensioning and fixation in this animal model. With anatomically more accurate ACL reconstructions that may (almost) fully restore normal joint mechanics, we can then begin to answer the question “Does postoperative joint stability result in lower incidence of OA?”

REFERENCES: