Quantitative In Situ Analysis of the Human Anterior Cruciate Ligament and Midsubstance Cross Sectional Area

Yoshimasa Fujimaki, MD, Ph.D.1,2, Eric Thorhauer1, Christopher D. Murawski1, Yusuke Sasaki1, Patrick Smolinski1, Scott Tashman, Ph.D1, Freddie H. Fu, M.D.1.

1University of Pittsburgh Medical Center, Pittsburgh, PA, USA, 2Showa University, Tokyo, Japan.

Disclosures:

Introduction:
Advancing knowledge of the anterior cruciate ligament (ACL) anatomy has led to the development of improved reconstruction techniques that better restore the anatomy of the native ACL. Anatomic ACL reconstruction is defined as the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites [1]. Graft choice and graft size are crucial to achieving anatomical ACL reconstruction while avoiding subsequent impingement within the inter-condylar notch, and having a maximal strength.

There is currently no consensus or standard for measuring the cross-sectional area (CSA) of the native ACL with respect to position or knee bending angle. To measure a soft tissue structure like ACL, measurement under simple dissection neglects the effects of physiological tension, making it difficult to evaluate the true in situ dimensions. Furthermore, no other studies have been published regarding the relation between the knee bending angle, as well as the end-to-end distance of the ACL and the CSA of the ACL.

The purpose of this study was to investigate the shape and size of the human ACL quantitatively, and evaluate the change in length of ACL and CSA at the midsubstance as a function of flexion angle and applied load.

Methods:
Data acquisition:
Eight human cadaveric knees (mean age 57.5±8.0 years) with no signs of osteoarthritis, previous injury or surgery were used in this study. Initially, a six degrees-of-freedom robotic arm (CASPAR Stäubli RX90 : Orto MAQUET, Rastatt, Germany.) was utilized to record the normal tibio-femoral kinematic paths for three loading conditions: unloaded, anterior tibial translation load of 89N (ATT) and combined simulated pivot shifting of 7-Nm valgus and 5-Nm internal rotation torque (PS)[2]. Once the kinematic paths were defined, the knee was carefully dissected with the aid of loupes to preserve only the ACL attachments to the femur and tibia. The overlying surface membrane around the ACL was carefully removed to clarify the footprint.

The specimens were then remounted onto the robot and moved through the previously recorded kinematic pathways. A 3D laser scanner (Faro Arm; Faro, Lake Mary, FL) was used to acquire the surface data of the ACL at 0, 30, 60 and 90 degrees of knee flexion with unloaded and under applying of ATT load, and at 0 and 30 degrees under applying of PS load. ACL insertion site boundaries at both femur and tibial attachment were also digitized using a 1 mm sized round-tipped ball probe on the Faro Arm to estimate the length of the ACL.

Data analysis:
Collected 3-dimensional data were then analyzed using Geomagic software (Geomagic, Research Triangle Park, NC). End-to-end distances between the centroid of each insertion site boundary were estimated as a length of the ACL [3]. Best-fit shaped cylinders were then applied to the surface data of the ACL at each state. From this, the axis of the cylinder was set as the axis of the ACL. CSA was measured on the plane vertical to its axis and in 1mm increments along this axis. Finally, the minimum CSA and its position between the centroids of each insertion site boundaries were determined (Fig1). Statistical analysis was performed using two-factor repeated-measures analysis of variance (ANOVA) with a significance level of P<0.05.

Results:
In all specimens, the ACL was shortest in length at 90 degrees of knee flexion (25.1±13.2mm) and serially elongated with extension, up to 18.8±10.1% at 0 degrees (29.7±3.0mm). Length also significantly increased 12.3±4.9% with the application of ATT load, and 7.65% with the PS load (Fig2a). The shape of the ACL was found to have its isthmus consistently at 53.8±5.5% of its length from the center of tibial attachment. CSA of the ACL at its isthmus was smallest with the knee extended (39.9±13.7mm2) and increased with flexion (43.7±12.1mm2). Equivalent circular diameters were 7.0±1.4mm and 7.4±1.1mm, respectively (Fig2b). There was no statistical difference of enlargement between 60 and 90 degrees compared to 0 degrees (10.0% and 9.5% respectively).

Discussion:
The shape of the ACL has been known to have an hour-glass like shape and expand onto its insertion to both the femur and tibia
Establishing the data analysis process to measure the CSA of the ACL using the data acquired by laser scanning system enables non-contact in-situ measurement at a desired position. In this study, we found that the ACL had its isthmus consistently located at 53.8±5.5% of its length from the tibial insertion.

The majority of past studies measured the size of the ACL at a single knee flexion angle, or made measurements after bony attachments were cut away. The strength of our study over this issue was that taking the physiological kinematic pathway for each specimen and reproducing the relationship of Femur-ACL-Tibia composite after dissection makes it possible to obtain true dynamic transformation in shape of ACL according to the knee flexion and application of various loads. The cross-sectional area of the ACL increased up to 14.4% while ACL length decreased up to 18.8% with increasing knee flexion angle.

Significance:
By performing measurements along the entire graft and accounting for effects of both load and knee flexion angle, this study addresses previously neglected factors for evaluating the true in situ mid-substance size of the ACL. Results of this study can be valuable for surgical planning, specifically for choosing graft size and fixation angle that most closely matches native anatomy and function across the entire range of knee motion.

Acknowledgments:

References:
Fig 1. Laser scanned image and schematic view of measurement. CSA was measured in a plane vertical to the long axis of the ACL.

Fig 2. a) Length and b) CSA of the ACL at each flexion angle of the knee and each loading condition.

ORS 2014 Annual Meeting
Poster No: 0811