Relationship between Knee Flexion at Heel-Strike of Walking and the Location of Thickest Femoral Cartilage in ACL Reconstructed and Contralateral Knees

INTRODUCTION:
It has been suggested that the spatial variations in the morphology and mechanical properties of articular cartilage are conditioned to the cyclic loading during ambulation [1]. Specifically it has been shown that regional variation in healthy femoral cartilage thickness distribution is associated with knee flexion during walking, where the thickest femoral cartilage was more posterior in knees that were more flexed at heel-strike [4]. Given the role of the anterior cruciate ligament (ACL) in guiding flexion-extension of the knee during walking, it is possible that individual variations in the patterns of knee flexion at high load phases (e.g. heel-strike) of the gait cycle would influence the normal distribution of cartilage thickness [1]. Assessing knee flexion in the context of a potential pathway to cartilage degeneration is important since it has been reported that 25% of patients have at least 5º of knee extension loss after ACL reconstruction [5].

Thus, the goal of this study was to test the hypothesis that the anterior-posterior (A-P) location of the thickest cartilage in the medial and lateral condyles of the femur will be correlated with knee flexion at heel-strike of walking for both ACL reconstructed and healthy contralateral knees. It is hypothesized that the thickest femoral cartilage will be more posterior in knees that are more flexed at heel-strike.

METHODS:
Twenty-nine subjects with clinically successful unilaterial ACL reconstruction and no other history of serious lower limb injury (avg 28.7±6.3 yrs, 1.7±0.1 m, 72.9±12.1 kg, 15 male, 2.6±1.9 mo injury to surgery, 26.9±3.7 mo post surgery, 91.8±6.5 Lysholm) were recruited for the study after providing IRB-approved informed consent. The knee flexion angle at heel-strike and mid-stance during level walking was measured using the previously described point cluster technique for both the reconstructed and contralateral knees [2].

The locations of thickest cartilage in the femur were determined from 3D femoral cartilage models created by segmentation of MR images (3D SPGR, 1.5T) with custom software [3]. A cylinder was fit to the 3D model and the femoral cartilage thickness values were projected onto the cylinder (Fig. 1). To determine the location of thickest cartilage in the medial and lateral femoral condyles, regions of interest were manually selected and a modified weighted average location (centroid) was determined using cartilage thickness as the weight (Fig. 1).

Linear regression (α = 0.05) was used to examine the relationship between the A-P position of thickest medial and lateral femoral cartilage and knee flexion at heel-strike.

RESULTS:
The A-P location of the thickest medial femoral cartilage was positively correlated with knee flexion at heel-strike for both the reconstructed (R²=0.274, p=0.003) and contralateral knees (R²=0.343, p=0.003) (Fig. 2). In these regions of femoral cartilage, the thickest cartilage was more posterior in subjects with greater knee flexion. The location of the thickest lateral femoral cartilage was not correlated with knee flexion.

Figure 3 demonstrates that the reconstructed knees (-1.5±4.2º) were significantly (p<0.001) more flexed at heel-strike than the contralateral knees (-4.6±3.4º). However, there was no change in the average location of the thickest cartilage in the medial (reconstructed 33.5±11.5º, contralateral 34.1±9.6º) or lateral (reconstructed 53.4±5.5º, contralateral 54.6±6.2º) femoral condyles.

DISCUSSION
The results of this study support the hypothesis that an individual’s A-P location of thickest femoral cartilage will be correlated with their knee flexion during walking. In the medial condyle, the thickest cartilage was more posterior in knees that were more flexed during walking (Fig. 2) indicating that the cartilage thickness distribution in the medial compartment had adapted over time to the subject-specific ambulatory mechanics. The fact that the relationship was not found in the lateral femoral condyle is in agreement with previous studies [4] and is likely attributed to the geometry of the lateral articulating surfaces and the resulting lack of inter-subject variation in thickness distribution.

The finding that the correlation between kinematics and morphology in the ACL reconstructed knees still existed 2 years post-op suggests that this patient population did not have large enough overall kinematic change to entirely disrupt this fundamental characteristic of healthy cartilage. However, 8 of the 29 patients had side-to-side knee extension differences greater than 5º, which resulted in a significant group difference in the mean knee flexion at heel-strike between the reconstructed and contralateral knees. Yet there was no associated change in the location of the thickest cartilage between the knees suggesting that the cartilage thickness distribution is not adapting to the change in tibiofemoral kinematics which is consistent with the limited adaptation potential of mature cartilage. Given that medial femoral cartilage is conditioned over time to its local mechanical environment (Fig. 2), these results provide a potential mechanism for the increased incidence of medial compartment osteoarthritis in this population. An acute kinematic change after ACL injury could cause the loading to shift to unconditioned regions of cartilage not capable of adapting to the loads experienced during ambulation thereby initiating biological changes ultimately resulting in cartilage degeneration. Taken together, these findings highlight the clinical importance of restoring normal tibiofemoral kinematics following ACL reconstruction.

REFERENCES