INTRODUCTION:
It is well understood that disruption of the knee’s anterior cruciate ligament (ACL) increases joint laxity in the anterior-posterior (AP) direction. However, the extent to which abnormal tibiofemoral translation occurs during activity remains unclear. Since pathological joint motion has been postulated as a contributor to changes in articular cartilage which may lead to osteoarthritis, determination of tibiofemoral translation during activity in ACL deficient patients is clearly of interest. The objective of the current study is to determine whether differences in anterior-posterior joint translations are observed between the normal and uninjured knees of ACL deficient patients as they perform a closely controlled experimental task.

METHODS:
The method for acquiring the kinematic data is based on modeling the trajectories of the femur and tibia as observed in a sequence of cine phase contrast (cine-PC) MR images. Cine-PC MRI was developed for the visualization of blood flow in the circulatory system; it has since been applied to the study of musculoskeletal biomechanics. A new processing technique has been developed in order to optimize the tracking of bony segments. The technique allows the detailed kinematics of the joint to be studied non-invasively during active joint function.

Fourteen subjects, who had each sustained an isolated rupture of the anterior cruciate ligament of one knee, participated in this study. All subjects read and signed a statement of informed consent which was approved by the University of Delaware’s Human Subject Review Committee.

The experimental activity was a repetitive knee flexion/extension exercise, performed while the subject lay supine within the bore of an MRI scanner (GE Signa LX). The thigh was placed on a ramp to put the hip in a flexed position, and knee extensions were performed against the weight of the shank only. The ramp was adjusted until the knee was fully extended as the toe just touched the highest point of the imager’s bore. The MR signal receiving coils were secured vertically, adjacent to each side of the knee, using a custom-made jig. The subject was instructed to flex and extend the knee through the available range of motion, at a frequency of 35 cycles per minute. An optical trigger, positioned under the heel of the subject, was used to synchronize the acquisition of data with the motion.

A sequence of 24 frames of cine-PC data was collected through the motion cycle on a user-specified sagittal image plane. Each resulting data frame yielded four separate images on the selected plane; one was an anatomical cross-section (magnitude image), and the others were encoded with velocity in three orthogonal directions.

The graphical models of the surfaces of the distal femur and proximal tibia were created from a sequence of high resolution axial plane static MR images. The periphery of each bone was traced on the 3D MR images using a digitizing tablet. Custom developed software was used to reconstruct the polygonal graphical models.

The cine-PC MR images show lines of low signal around the edge of each bone’s intersection with the image plane. An initial estimate of the location of the bone was made by intersecting the geometric model with a virtual cutting plane in various position and orientations. The difference between observed and virtual cross-sections was minimized computationally. Using this procedure, a region of interest of each sagittal image was extracted which contained only points lying within the bone of interest. Using these velocity data, and invoking the relationships between the motions of particles within rigid bodies, the angular and linear velocities of each bone were estimated. An iterative procedure minimized the error between the apparent velocities produced by a modeled trajectory of the rigid body and those observed in the velocity data set.

Anatomically based coordinate systems were fixed within each bone. Landmarks were digitized in the sagittal images in order to establish the directions of the long axes of the femur and tibia in that plane. Using the graphical model, a plane was aligned with the most distal edges of the femoral condyles, the alignment of the long axis in the frontal view was perpendicular to this. The medial-lateral axis was then aligned parallel to the posterior edges of the condyles, and the AP axis was found as the mutual perpendicular of these two axes. For the tibia, the direction of the long axis in the frontal view was set perpendicular to a plane approximating the tibial plateau. The medial-lateral direction was set parallel to the posterior borders of the tibia and fibula.

The coordinates of the most distal point in the femoral notch and the tibial eminence were determined in the graphical models. Following the method of Grood and Suntay, the vector from the femoral notch to the tibial eminence was calculated. The anterior-posterior translation parameter was calculated as the projection of this vector along the mutual perpendicular of the medial-lateral axis of the femur and the long axis of the tibia.

RESULTS:
In Figure 1, the averaged translation parameters in the ACL-deficient and uninjured groups are compared. The ACL-deficient group exhibits increased anterior translation relative to the uninjured side. The peak value of the averaged side to side difference in translation was 1.1mm. A two-tailed t-test for differences in peak translation between the groups yielded a significance level of p=0.088. It is expected that statistical significance (p<0.05) will be achieved as the experiments continue on additional subjects.

DISCUSSION:
This study presents a novel method of in vivo measurement of joint kinematics that is non-invasive and allows direct visualization of bony segment motion. The results of this study suggest that the increased laxity resulting from injury of the ACL carry through to an increase in joint translation in active joint function.

It has been reported previously that some ACL-deficient patients are able to maintain functional stability in spite of their injuries. It is the goal of our ongoing research to determine the potential for non-operative treatment of ACL injuries by elucidating the dynamic stabilization strategies used by such patients. Electromyographic data on muscular activation is being acquired while subjects perform the experimental task described here. By combining these two techniques, we expect to be able to account for the effects that muscular activity has on joint motion.

REFERENCES:

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Figure 1: Averaged change in AP translation parameter plotted versus flexion angle for ACL-deficient knees, compared with the uninjured group. Anterior translation is positive.