INTRODUCTION:
Anterior cruciate ligament (ACL) injury has been shown to alter knee kinematics [1,2] within the joint and as a consequence may contribute to increased risk of developing knee osteoarthritis [3]. Determining the changes in tibio-femoral contact in ACL deficiency is essential to understand why this degeneration of the knee joint occurs. This study directly compares in vitro kinematics in intact cadaver specimens to tibio-femoral contact after simulated ACL rupture/deficiency using both open chain and closed chain analyses. It is hypothesized that 1) the ACL deficient (ACLD) knees will have greater anterior motion of the tibia compared to the femur and therefore femoral contact will be positioned more posterior on the tibia compared to the normal knee trials 2) a greater difference in contact position between the normal and ACLD trials will be determined in the closed chain compared to the open chain trials.

METHODS:
Four lower extremity cadaver limbs with no prior surgeries, deformities, or disease were prepared by removing the soft tissue from the hip to 4 inches proximal to the patella. Radio-opaque (methylmethacrylate bone cement) markers were rigidly placed on landmarks of the femur, tibia and patella. A full limb CT scan was acquired of each specimen and the images were processed using Mimics and 3Matic software (Materialise, Belgium) to isolate the bones and markers from the surrounding soft tissue, and 3D solid CAD models were created using Solidworks software (Dassault System, Concord, Massachusetts).

During closed-chain experimentation, the foot and femur were securely fixed in the custom knee device, designed to record loads and simulate a squatting motion from full-extension to deep flexion (≈115°) and back to full-extension. Open-chain experimentation was performed by securely fixing the femur in a custom device where the foot was free to move and a full range of motion could be acquired. The knee was articulated through a range of motion by a tether sutured to the quadriceps tendon and driven by an actuator. Rigid body arrays of infra-red (IR) emitters were attached to the femur, patella and tibia and were connected to an Optotrak Certus (NDI, Inc., Waterloo Ontario) three-camera motion capture system. The bone markers were digitized and registered to the motion capture system using a rigid array of IR emitters attached to a probe tip that allowed correlation of recorded motions to CT coordinates. Three-dimensional kinematic data were recorded and combined with the CAD models to evaluate joint kinematics through tibio-femoral contact points.

Three trials of the normal knee were performed through a complete range of motion in the open chain device, followed by three closed chain trials simulating a squatting motion. After acquiring kinematic data from the normal intact knee, the ACL was completely resected, to simulate deficiency, and the joint was sutured closed. Three open chain and three closed chain trials were then acquired of the ACLD knee.

Medial and lateral tibio-femoral contact points for each trial were evaluated at 5 degree increments of flexion, using a closest point approximation for the normal knee and ACLD trials. The trials were analyzed for both flexion to extension, and extension to flexion. The change in medial and lateral anterior/posterior (AP) position between the normal and ACLD trials were calculated, where a negative translation corresponds to a more posterior contact position for the ACLD trials compared to the normal. Differences between open chain and closed chain AP contact translations of the normal to ACLD trials were compared using parametric paired t-tests (α = 0.05). Based on system error, non-zero translations were determined if the difference in contact position between the normal and ACLD trials were greater than 1mm.

RESULTS:
Average lateral tibio-femoral contact position is more posterior in the ACLD trials compared to the normal. A greater difference in contact position between the normal and ACLD trials was observed for flexion of both the open chain and open chain analysis. Average medial tibio-femoral ACLD contact position is more posterior for the closed chain analysis from full-extension to 100°, and translation is greater than 1mm from full-extension to 50°. Open chain analysis confirmed for medial contact from approximately 0° to 40° degrees of flexion, whereas the medial and lateral translations were in the opposite directions. As hypothesized, lateral tibio-femoral contact position was more posterior in the ACLD trials for both the open and closed chain analysis. This anterior translation produces a greater internal rotation in the open chain trials, suggesting that the ACL not only controls anterior/posterior position but also internal/external rotation. The second hypothesis was only confirmed for medial contact from approximately 0° to 40° degrees of flexion. It was theorized that the closed chain would produce larger contact translations because of the greater force being applied across the joint, but our results suggest that the opposite may be occurring where the additional force acts as a stabilizing factor. This decreased stability is additionally detected in the open chain analysis because the medial and lateral compartment translations were in the opposite directions resulting in increased internal rotations; whereas the medial and lateral translations for the closed chain analysis were in the same direction. The current kinematic analysis highlights the variability that exists between different analysis modalities.

DISCUSSION:
As hypothesized, lateral tibio-femoral contact position was more posterior in the ACLD trials for both the open and closed chain analysis, but contact on the medial compartment translation was opposite the hypothesized direction in the open chain analysis. This anterior translation produces a greater internal rotation in the open chain trials, suggesting that the ACL not only controls anterior/posterior position but also internal/external rotation. The second hypothesis was only confirmed for medial contact from approximately 0° to 40° degrees of flexion. It was theorized that the closed chain would produce larger contact translations because of the greater force being applied across the joint, but our results suggest that the opposite may be occurring where the additional force acts as a stabilizing factor. This decreased stability is additionally detected in the open chain analysis because the medial and lateral compartment translations were in the opposite directions resulting in increased internal rotations; whereas the medial and lateral translations for the closed chain analysis were in the same direction. The current kinematic analysis highlights the variability that exists between different analysis modalities.

REFERENCES: