INTRODUCTION:
The physical detriment and economic costs of anterior cruciate ligament (ACL) injury are well documented in the literature. Unfortunately, key risk factors and mechanisms of non-contact ACL injury have yet to be fully identified. A family of risk factors of increasing importance focuses on the geometry of the tibial plateau. One study of tibial geometry showed that depth of the medial plateau (MTD) and slope of the medial and lateral aspects of the plateau (MTS and LTS, respectively) can be used to estimate probability of injury. Additionally, tibial geometry has been shown to affect kinematics of the knee. Although studies have established that MTD, LTS, and MTS can be used to assess injury risk, the direct effects of these factors on ACL strain have yet not been reported. This study aims to show the effect of tibial geometry on ACL strain. Previous in-vitro studies of joint compression and ACL injury have rigidly constrained angular displacements of the tibia and femur, maintaining constant knee flexion. This approach may obscure any protective effects that joint compression has as the knee flexes. The present study further seeks to assess the influence of tibiofemoral compression on ACL strain in a dynamic activity where knee flexion is present.

It is hypothesized that during a simulated jump landing, steeper tibial slopes (MTS and LTS) will result in increased ACL strain. Further, knees presenting deeper medial tibial plateauus (MTD) will experience lower ACL strain. Additionally, it is hypothesized that increased pre-landing compression of the knee joint will lead to reduced ACL strain under simulated landing conditions. These hypotheses will be evaluated using an accepted in-vitro simulation technique and a purpose-built dynamic knee-loading simulator.

METHODS:
A dynamic knee-loading machine was designed and fabricated for the in-vitro simulation of various tasks with established risk of ACL injury, including jump landing. This apparatus allows for anterior-posterior-positioning of the hip and ankle. Additionally, initial knee flexion, and thus ankle and hip flexion, can be adjusted. Stepper motor-driven winches generate tension in drive cables attached to the patella and the proximal-posterior femur to generate muscle/joint forces. The machine also allows for the application of impulsive loads at the ankle to simulate impact and weight acceptance at landing. The machine was also used in conjunction with the Tekscan K-Scan pressure mapping system (Tekscan, Inc., Boston, MA) to measure joint forces arising from the application of muscle forces.

Nine fresh-frozen human cadaver knees were used in this experiment (7 M, 2 F; age: 52.6±12.0). Magnetic resonance images of the intact knees were obtained using a 1.5-T clinical MRI machine. From the MRIs measurements of MTS, LTS, and MTD were taken for each knee. All knee specimens included a minimum of 17.5 cm of bone proximal and distal the joint space. Following MR imaging, the knees were thawed, dissected to the capsule level, and examined for injury. Specimens were stored at -20°C until the evening prior to dissection/testing, when they were thawed overnight at room temperature. Each knee was installed in the machine and its ACL was instrumented with a differential variable reluctance transformer (DVRT) to measure ligament elongation/strain. The knees were then subjected to a series of nine simulated landings. Initial joint flexion angles (10°, 20°, 30°) and pre-landing joint compression were varied in each of these trials. Joint compression was induced through the application of simulated gluteus muscle forces (SGFs) at levels of 0 N, 100 N, and 200 N coupled with a constraint on inferior/posterior ankle displacement. The gluteus maximus is a hip extensor that, in conjunction with the imposed ankle constraint resists knee flexion. This antagonism increases joint force, as measured in six knees prior to the landing tests (figure 1). A quadriceps force of 200 N was also applied prior to each test. An impulsive ground reaction force was then applied. Multiple linear regression analyses were conducted to assess the extent of the relationship between ACL strain and MTS, LTS, MTD, and SGF within each flexion angle.

RESULTS:
Regression analysis revealed that tibial geometry and simulated gluteus force were significant regressors for at least one of the tested flexion angles. At 10° of initial knee flexion, medial tibial depth (MTD) and simulated gluteus force (SGF) were both related to significant decreases in ACL strain (p = 0.028 and p = 0.009). At 20°, increased MTD also negatively influenced ACL strain (p = 0.011) and lateral tibial slope (LTS) was associated with significant increases in ACL strain (p = 0.047). Similarly, at 30° of flexion, knees presenting higher MTD experienced lower ACL strain (p = 0.001); knees with increased LTS again saw greater ACL strain (p = 0.022). The standardized regression coefficients are shown in Table 1. It was also found that a strong relationship exists between increased gluteus force and joint force in the presence of constraints on ankle displacement (figure 1).

Table 1. Standardized coefficients (β) and p-values from regression within knee angle. The fs indicate the change in ACL strain due to one standard deviation change in the regressor. * denotes significance

<table>
<thead>
<tr>
<th>Variable</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
</tr>
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<tbody>
<tr>
<td>MTS</td>
<td>0.295</td>
<td>0.218</td>
<td>0.278</td>
</tr>
<tr>
<td>LTS</td>
<td>0.065</td>
<td>0.767</td>
<td>0.380</td>
</tr>
<tr>
<td>MTD</td>
<td>-0.380</td>
<td>0.028</td>
<td>-0.375</td>
</tr>
<tr>
<td>SGF</td>
<td>-0.415</td>
<td>0.009</td>
<td>-0.145</td>
</tr>
</tbody>
</table>

Figure 1. Increasing joint compressive forces (JCF) under increasing gluteus forces. Mean ± SEM.

DISCUSSION:
To the authors’ knowledge this is the first study to report the influence of tibial geometry on directly measured strain in the anterior cruciate ligament. The results of this study indicate that greater MTD is protective at all tested flexion angles. The posterior-decreasing slope of the lateral tibial plateau is a factor which exacerbates ACL loading at 20° and 30° of flexion. This is surprising and may indicate that the protective effect of MTD near full extension overcomes the detrimental effects of LTS. Finally, our results show that at 10° knee flexion, increasing joint compression (via the gluteus in this case) prior to landing also protects the ACL. We believe that this protective mechanism is due to compression-induced increases in joint congruence. The strong relationship between gluteus levels and joint force supports this assertion. We believe that even the mild amounts of pre-landing joint force utilized in this study are protective of the ACL during athletic activities when the knee is near full extension. This is consistent with the findings of another study which posited a similar protective effect due to the quadriceps muscles.

Our results show that flexion angle affects the dependence of ACL strain on tibial plateau geometry. We believe that this connection is extremely complex but crucial in understanding the true behavior of the knee. A limitation of our study is that we did not consider the interaction among the covariates. There may exist strong and complex interaction among MTS, LTS, MTD, and muscle forces that could possibly influence these results.

REFERENCES:
2. McLean et al. (2010), Clin Biomech (Bristol, Avon), [Epub Aop].