EFFECT OF TIBIAL ROTATION INHIBITION ON ACL INJURY AT DIFFERENT FLEXION ANGLES

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This study investigates the damages to the knee joint due to impact load and inhibition of tibia rotation. A rig was manufactured to test fifteen fresh porcine knee specimens replicating single leg landing. Three knee flexion angles (22.5°, 37.5° and 52.5°) were tested. For each angle, 5 specimens were fixed and consecutive displacement control loads with increments of 0.5 mm were applied to tibia until catastrophic failure happened. Anterior cruciate ligament avulsions were found in greater flexion angles but not at low flexion angles. No significant difference was observed in the following parameters in different knee flexion angles; peak compressive force, internal tibia torque, and posterior femoral displacement. Our results also suggest that an optimum tibia rotation may be needed to avoid ACL injury while its inhibition could lead to intrachondral fracture.

KEY WORDS: ACL injury, tibia rotation, bone fracture, in vitro.

INTRODUCTION: Anterior cruciate ligament (ACL) injury is one of the most debilitating sport injuries. About 70% of these injuries happen via non-contact mechanism. Landing from a jump accounts for majority of these costly ACL injuries. During landing, muscles co-activate in order to stabilize and decelerate the knee joint. The kinematics of the knee joint during landing includes the flexion/extension of the knee joint and rotational motions such as internal/external and varus/valgus, which can strain the ACL. For example, a combination of low flexion angle and motions in all planes could place the ACL at the risk of injury instead of one overarching motion such as the anterior tibia translation (ATT). Previous studies have focused on the role of multi-planar motions and ACL injury through simulation and cadaveric experiments, but few have focused on the effects of high impact loads. Internal/external tibia rotation has also been shown to exist at the onset of injury during landing (Olsen, Myklebust, Engebretsen, & Bahr, 2004). It is speculated that inhibition of tibia rotation with respect to femur could protect the ACL at low flexion angle. To investigate this further, we utilized in-vitro experiments to evaluate the effects of restricting tibia rotation. The results will provide more information to the design of assistive devices that restrict knee motion during impact such as knee braces. We hypothesized that inhibition of tibia rotation with respect to femur could protect the ACL at low flexion angle.

METHODS: A rig was designed and manufactured to simulate landing tasks. The constraints provided by the rig allow the following four degrees of freedom, relative movement of the femur with respect to the tibia (Figure 1): internal/external rotation of tibia, the vertical motion of the hip (provided to the tibia pot), and the hip horizontal motion (assigned to the femur pot by means of an X-Y table). A servo hydraulic machine (Instron 8874 UK) was utilized to apply an axial load in the direction of the long axis of the tibial shaft, with the knee held at the specific flexion angle by a rotational locking system attached to tibia pot. A set of screws were used to lock and unlock the tibia rotational movement with respect to the long axis of the Instron machine. The porcine specimens were fixed at three different flexion angles of 22.5, 37.5 and 52.5 degrees. Fifteen fresh porcine specimens (aged 6-9 months) were cut and secured in two cylindrical pots using plaster similar to the method described in previous studies (Yeow, Ng, Cheong, Lee, & Goh, 2009). To measure anterior tibial translation (ATT) and medial/lateral displacements, a magnetic tracking system (TrackStar model 180) was utilized to detect the horizontal displacement of the sensor attached to the femur pot, which corresponds with the displacement of the X-Y table (Figure 1). This sensor detects 3D translational displacement of an object in its field of operation.

External axial impact loads were applied using a single 10 Hz harversine to simulate vertical ground reaction forces (GRF) sustained during single-leg landing. These loads were displacement-controlled, and were applied at successive range of actuator displacements starting from 1.5mm with 0.5mm increment till catastrophic failure was observed. The tibia rotation was constrained through the locking mechanism. During each consecutive experiment, we collected external forces, tibial internal/external torque, tibia vertical displacement with respect to femur, anterior posterior displacements of femur with respect to tibia. The specimens were then removed from the fixture for dissection. The effects of the impact load on the knee joint as well as type of damages caused by such loading were visually observed and documented. One-way ANOVA was used to identify differences in the various tests variables (compressive force, torque and displacement) between the different flexion angles at the 0.05 level of significance.

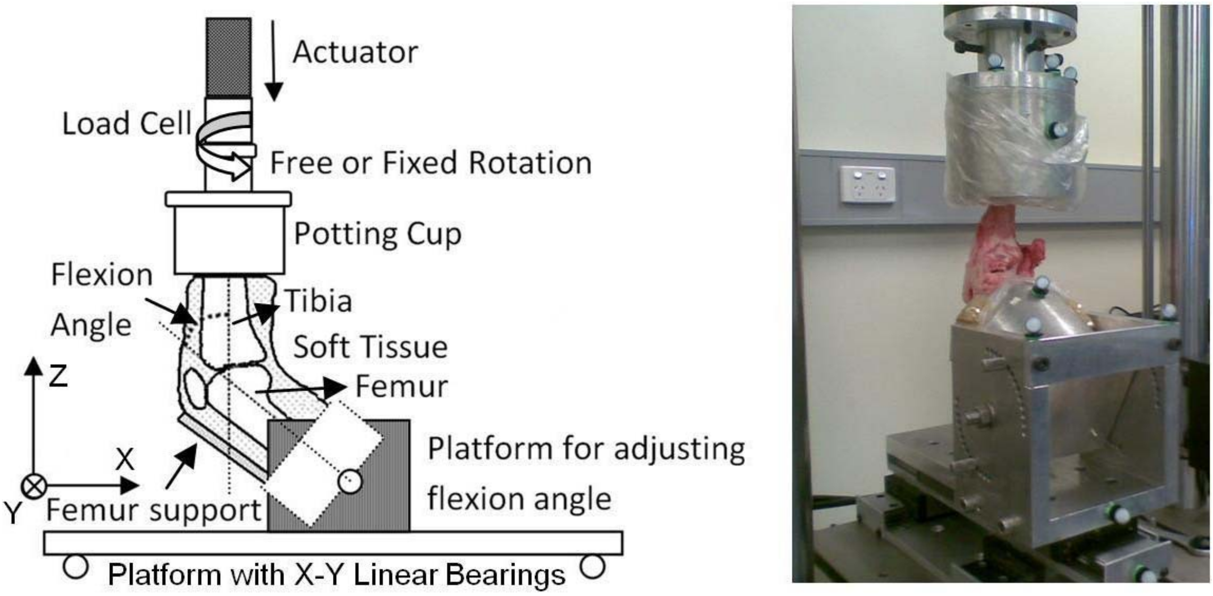

Figure 1: Impact test setup drawing (Left) with a soft tissue-intact porcine knee specimen (Right).

RESULTS: Maximum compressive load were found when testing at the lowest flexion angle of 22.5° and reached 9.5 kN on average. However, when compared to the maximum compressive forces at 37.5° and 52.5°, there was no significant differences ($p=0.182$).A drop in compressive force (kN) was noted at each trial where catastrophic failure occurred ($p=0.872$). This is the difference between the peak external load before and at the instant of catastrophic failure. Peak mean tibial internal torque was about 15 Nm and it did not change at different flexion angles ($p=0.911$). In addition, comparing the mean values of measured variables at catastrophic failure using one-way ANOVA showed that there were no differences among the mean values at catastrophic failure ($p=0.182$). Although the mean posterior femoral displacement (or ATT) increased as the flexion decreased, there were no differences among the means at the same level of significance ($p=0.225$) (Table 1).

In terms of damage type, at low flexion angle (22.5°) where most ligament injuries happed, it is shown that intrachondral fracture could occur when tibia rotation is inhibited (Figure 2). Two samples had fractures at femoral condyle, one with partial ACL tear and another with partial posterior cruciate ligament (PP) tear. At 37.5° there were three fractures on the femoral condyle and ACL avulsion occurred in one of the specimens (Figure 2). Two specimens were visually observed to be intact after dissection. At 52.5° flexion angle, two femoral avulsions of ACL were detected. Of the five specimens, two femoral condoyle were observed while one specimen didn't present visible failure to the bones or ACL.

Table 2: Type of damages when catastrophic failure ocured or a poping sound was heard. Peak compressive forces, drop in compressive forces, peak internal torques, Posterior Femoral Displacement and Lateral Femoral Displacement for all specimens at 22.5°,37.5° and 52.5°. *Not used statistical analysis as no failure was observed. ND: No visible damage, AF: Avulsion at femur, FF: Fracture at femur, ACL_P: ACL tear partially, PP: PCL tear partially, TS: Tibia Shaft fracture, C: Cement fracture.

Specimen		Failure Type	Peak Compressive Force (kN)	Drop in Compressive Force (kN)	Peak Internal Torque (Nm)	Posterior Femoral Displacement (mm)
52.5°	1	ND	8.54	-0.02	11.82	5.25
	2	AF	5.57	2	5.73	13.17
	3	FF	7.6	1.53	11.86	5.13
	4	FF	8.88	2.92	23.59	6.36
	5	AF	9.23	2.84	14.48	7.93
Mean ±SD			7.96 ±1.47	1.85 ±1.20	13.50 ±6.50	7.57 ±3.33
37.5°	1	FF	9.92	2.17	18.23	0.11
	2	FF&AF	6.48	2.41	18.42	8.93
	3	ND	6.95	0.33	16.92	0.11
	4*	ND	12.16	-0.58	34.57	7.14
	5	FF	6.15	0.91	7.43	1.12
Mean ±SD			7.37 ±1.73	1.45 ±1.00	15.25±5.26	2.57 ±4.27
22.5°	1	FF	8.5	1.19	17.92	4.69
	2	ND&C	7.95	0.34	12.91	32.04
	3	FF	11.51	7.18	16.75	9.93
	4	ACL_P	9.69	-0.08	14.5	3.68
	5	PP&TS	9.69	0.25	11.42	0.11
Mean ±SD			9.47 ±1.37	1.78 ±3.06	14.70 ±2.67	10.09 ±12.76

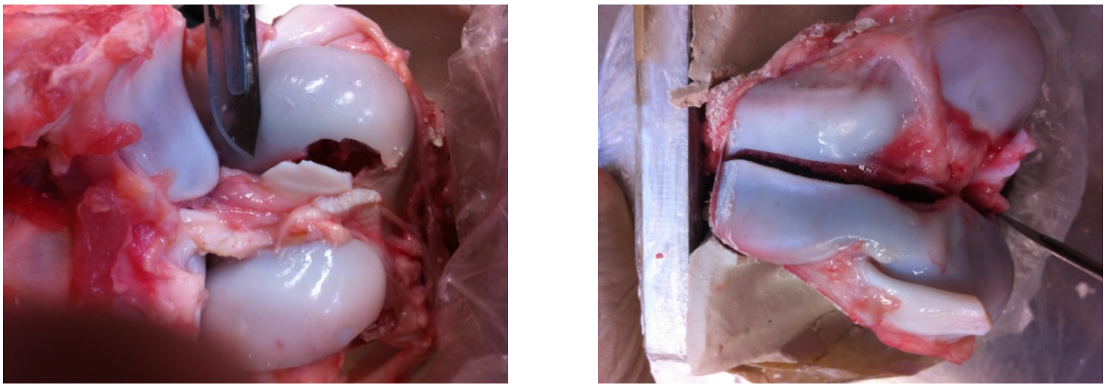

Figure 2: ACL avulsion at femur (Left), intrachondral fracture at femur (Left).

DISCUSSION: In this study we investigated the effects of high impact load analogous to a single leg landing and the types of damages on the knee joint when the tibia rotation was constrained. Using an In-vitro porcine experiment, we found that the inhibition of tibial rotation may increase knee joint forces compared to similar previous studies (Yeow et al., 2009). More avulsions (40% of the samples) were found in greater flexion angles while there was not any AF at low flexion angle. Also, there were no significant differences between mean values of peak compressive force, peak internal torque, posterior femoral displacement and lateral femoral displacement in all flexion angles; however the damages incurred on the joint were different. We may then conclude that similar loading could cause different injuries at different flexion angles. This may occur due to differences between distribution of loading on lateral and medial parts of the knee joint during landing.

ACL injuries are associated with excesive knee joint internal rotation during landing. Also, combination of the tibial rotation as well as valgus motion could strain the ACL more than the effect of each motion separately (Quatman, Quatman-Yates, & Hewett, 2010). Thus we prevented tibia rotation and speculated that this may reduce the negative effect of combinatory rotations in non-sagittal plane. Although greater GRF was needed to cause ACL rupture i.e. landing without internal tibia rotation could possibly prevent ACL injury, as we hypothesized, other types of damages to the joint, such as intracondylar notch fracture, resulted due to the inhibition of the tibia rotation. As a result, we could possibly speculate that some internal tibial rotation may be needed to avoid both ACL tear and intracondylar fracture. Therefore, the optimum tibial rotation that may help protect the knee joint damage could be an area of future study.

Prior to catastrophic failure, tibia internal torques increased as we applied greater axial compressive load. However, these torques are small when compared to what the muscles could generate during a single leg landing (i.e. arresting any unwanted internal rotation). As a result, muscles may be able to inhibit tibia rotation at the onset of injury. It can be speculated that during landing the knee joint allows tibia rotation in an attempt to avoid high joint forces that may cause the type of damages we see in this study. However, any additional tibia rotation plus valgus and ATT motion could lead the knee joint to “a point of no return’ in which ACL injury becomes inevitable.

CONCLUSION: This study identified different types of damages present in tibial-rotation-constrained knee joints at different flexion angles during high impact loading similar to a single leg landing. To avoid debilitating injuries such as ACL and bone fracture, an optimum tibia rotation may need to be provided during landing at different flexion angles. As a result, evaluation of safe tibia rotation should be noted in training methods as well as brace designs to protect the knee joint during landing.

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