KNEE JOINT RELATIVE MOTION DURING ACL RUPTURE BY INTERNAL TIBIAL TORSION OR TIBIOFEMORAL COMPRESSION

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INTRODUCTION

The knee is one of the most frequently injured joints in the human body. Approximately 91% of ACL injuries occur during sporting activities, usually from a non-contact event (Paul, 2003). The most common kinematic scenarios for ACL injuries are internal twisting or combined loading during a hard landing (Ettlinger, 1995). Biomechanical studies confirm that the ACL is a primary stabilizer of the knee for internal tibial rotation (Markolf, 1995) and TF joint compression (Torzilli, 1994), especially between full extension and 30° of flexion. ACL strain measurements *in vivo* show similar magnitudes between weightbearing loads of 40% and 10 Nm of internal tibia torque (Flemming, 2001). Few studies however, have documented relative knee joint displacements at failure levels of force. The goal of the study was to induce ACL rupture in the knee joint by isolated internal tibial torsion or TF compression and measure the relative joint motions that occur prior to, and following, the injury. These relative motions of the knee joint may be important for the interpretation of injury mechanisms from video-based studies of clinical ACL tears.

METHODS

Experiments were conducted on 20 cadaver tibiofemoral (TF) joints (53.5 ± 7.9 yrs). The bone ends were potted in cylindrical aluminum sleeves. For both compression and torsion experiments the flexion angle was fixed at 30° and the femur was attached to an X/Y translational table that had linear encoders attached to record anterior/posterior as well as medial/lateral motions relative to the tibia. Compression was applied axially through the tibia via repeated, increasing load tests until catastrophic injury of the joint. In one series of experiments (C1, n=7) axial rotation of the tibia was unconstrained and internal/external rotation was recorded with a rotary encoder, but varus/valgus rotation was prevented. The opposite, paired joints from this series of experiments were loaded with an internal torque (T) that was applied through the tibia with a similar repeated loading protocol. Femur varus/valgus rotation was unconstrained and recorded with a rotary encoder. In a second series of experiments (C2, n=6), TF joints were also loaded in compression, similar to C1, with the exception that femur varus/valgus rotation was unconstrained and recorded, but tibia internal/external rotation was prevented. The peak forces and relative joint motions were documented from the tests immediatedly prior to failure (SF) and during failure (F). Statistical t-tests were used to test for significant differences ($p < 0.05$).

RESULTS AND DISCUSSION

Internal tibia rotation produced a coupled posterior and lateral displacement and valgus rotation of the femur (Table 1). The results for the two series of compression experiments were similar and also showed posterior femur displacements. However, when axial rotation of the tibia was allowed there was a slight medial motion, but when varus/valgus rotation was allowed there was lateral motion of the femur. Most of the displacements produced significantly higher magnitudes in F tests than SF tests with one notable exception. There was internal tibia rotation in C1 experiments before ACL failure, but after failure the rotation switched to external. The largest increase in displacement after failure for compression was posterior displacement of the femur.

All failures involved the ACL, although there were frequently other ligamentous or meniscal injuries. The compressively loaded specimens had a peak load of 6.0±1.9 kN, while the torsionally loaded specimens failed at 37.4±16.8 Nm. Avulsion fractures occurred in 7 specimens and there were significant differences between the failure loads in these versus midsubstance failures for compression experiments (6.8 versus 4.3 kN), but not for torsion experiments. The displacement values were similar between injury types (p values between 0.18-0.37).

Table 1. Average (SD) for compression and torsion experiments. # Difference between SF and F, * difference between C1 and C2.

		Compressive Load (kN)/ Torque (Nm)	Posterior Femur Displacement (mm)	Lateral Femur Displacement (mm)	Internal Tibia Rotation (Deg)	Valgus Femur Rotation (deg)
C1	SF	5.0 (1.9)#	12 (5.2)#	-2.1 (4.8)	3.9 (4.0)#	
	F	5.4 (2.0)	27 (15)	-1.5 (8.1)*	-6.1 (4.3)	
C2	SF	5.8 (1.6)#	12 (4.3)#	0.1 (2.1)#		1.3 (3.2)#
	F	6.7 (1.6)	24 (9.7)	5.6 (3.9)		8.0 (3.6)
T	SF	36 (14)#	8.4 (3.3)	6.3 (5.1)#	46 (16)#	11 (6)#
	F	37 (17)	10 (4.1)	11 (4.0)	58 (18)	20 (5.7)

SUMMARY/CONCLUSIONS

Our laboratory has previously documented ACL rupture from TF compressive loading for knee flexion angles of 60, 90 and 120° (Meyer, 2005). The current study provides new information for important joint motions, such as the maximum anterior drawer and internal rotation of the tibia, that occur prior to injury. During compression, the femur displaced posteriorly relative to the tibia in SF tests and with a significantly higher magnitude in F tests (Figure 1). Others have also documented a similar "anterior neutral shift" of the tibia during weightbearing (Torzilli, 1994) that could predispose the ACL to rupture. In C2 and T experiments there was a significant increase in valgus angular displacement after ACL failure. The study confirmed that joint motions can vary before and after failure of the ACL. There was also approximately 4° of internal tibia rotation before failure, but 6° of external rotation after. External tibial rotation and valgus joint motions are frequently documented in video analyses of sports related ACL injuries. However, the exact time when the ACL ruptures is unknown (Olsen, 2004). The current study may suggest these video documented motions actually occur after rupture of the ACL.

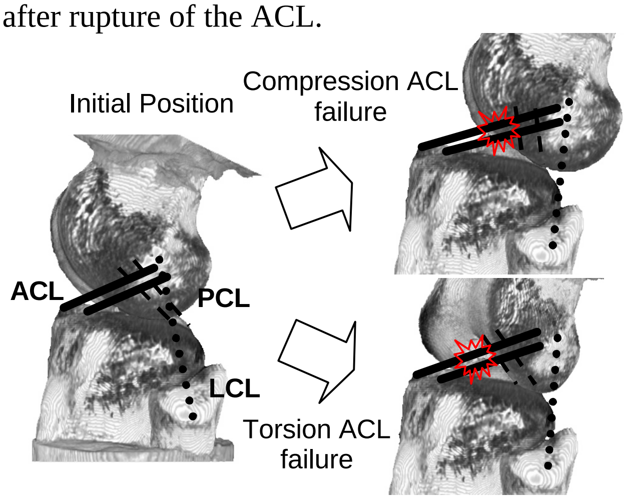

Figure 1. Sagittal view, for a fixed tibia, of the relative TF joint motion.

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