ANTERIOR CRUCIATE RUPTURE DUE TO EXCESSIVE INTERNAL TORQUE OF THE HUMAN TIBIA

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INTRODUCTION

The knee is one of the most frequently injured joints in the human body. Epidemiological studies have shown there are over 80,000 anterior cruciate ligament (ACL) tears in the USA each year, with a total cost of one billion dollars (Griffen, 2000). Many clinical studies have proposed the loading mechanisms that cause injury to the ACL. In one study of 361 ACL patients, 78% were from athletic activities, primarily football and basketball, and approximately 82% of the patients could describe the injury mechanism as internal tibial rotation (Arnold, 1979). Skiing in particular, has one of the highest rates of ACL injuries, accounting for 25-30% of knee injuries (Speer, 1995). These injuries are mainly associated with internal twisting or combined loading during a hard landing (Ettlinger, 1995). In fact, biomechanical studies have shown that internal tibial torque is an important loading mechanism of the ACL (Markolf, 1995), especially when the knee is between full extension and 30º of flexion. The hypothesis of the current study was that the primary injury in an isolated human cadaver knee joint under excessive internal torsion would be isolated ACL rupture. Unlike previous experimental knee torsion studies, the proposed experiments would allow normal unconstrained joint motion of the knee in all the degrees of freedom with the exception of flexion and the applied internal rotation of the tibia.

METHODS

Torsion experiments were conducted on seven cadaver tibiofemoral joints (55.8 ± 5.7 yrs) that were sectioned 15cm proximal and distal to the center of the knee. The femur and tibia shafts were cleaned with 70% alcohol and potted in cylindrical aluminum sleeves with room temperature curing epoxy. The tibia was attached to a rotary hydraulic actuator through a biaxial (torsion-axial) load cell. The femur was placed in a fixture that allowed the joint flexion angle to be set at 30º while the varus/valgus angle was left unconstrained and recorded with a rotary encoder. This fixture was attached to an X/Y translational table that had linear encoders attached to record anterior and posterior as well as medial and lateral motions of the femur relative to the tibia. The X/Y table was in turn attached to a rotation-locked, linear hydraulic actuator and a compressive preload of approximately 1000 N was applied. Repeated, increasing levels of internal torque where applied to each specimen until catastrophic injury of the joint. Additionally a CT scan of each specimen was acquired and the bone mineral density (BMD), in Hounsfield units (Hu), was measured from trabecular bone regions on the medial and lateral tibial plateaus using coronal slices. Statistical t-tests were used to test for significant differences, where $p < 0.05$.

RESULTS AND DISCUSSION

Four of seven knee joints suffered ligamentous damage including a complete or partial ACL rupture at 45.7 ± 14.9 Nm. The remaining three joints suffered avulsion fractures at the ACL insertion into the tibia at a lower peak torque of 26.3 ± 13.9 Nm ($p=0.07$). The BMD was significantly higher in specimens with ligamentous rupture versus avulsion fracture ($p=0.001$). BMD values were 163.5 ± 58.7 Hu versus 61.3 ± 17.9 Hu, respectively. The failure torque and

BMD also showed a slight correlation using linear regression (Figure 1). Torque values from all the tests were used in a logistic regression analysis to predict the 50% likelihood of joint failure (Figure 2). The compressive load, rotation and displacement values were similar between injury types (p values between 0.18-0.37) so the average for all specimens is reported. The average external rotation at joint failure was 66.6 ± 17.3° and the average valgus rotation was 20.3 ± 5.7°. There was 10 ± 4.1 mm of posterior motion of the femur relative to the tibia. The linear actuator moved 7.4 ± 4.9 mm proximally in order to compensate for small drops in the compressive preload.

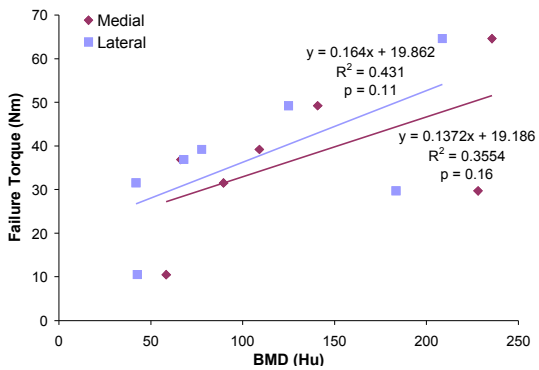

Figure 1.Linear regression.

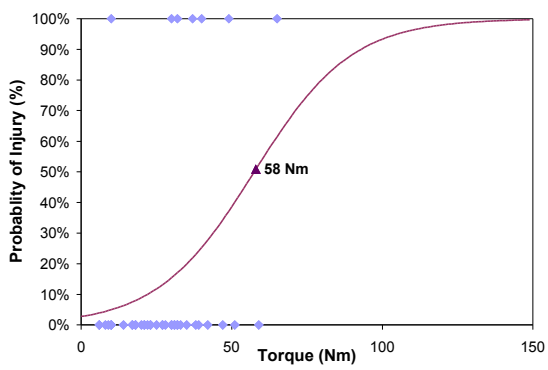

Figure 2. Logistic regression.

SUMMARY/CONCLUSIONS

The current study showed that ACL injuries occurred at torques of approximately 37 Nm applied to the tibia. Our laboratory has previously documented ACL rupture with approximately 5 kN of tibio-femoral compressive loading. Others have also noticed a similar "anterior neutral shift" of the tibia with respect to the femur during weight bearing (Flemming, 2001) that could predispose the ACL towards rupture. A combined loading scenario with higher joint compressive loads than applied in the current study may in fact reduce the peak torque required to cause ACL injury. However, muscle contraction also plays an important role in sports related injuries and male subjects have been shown to voluntarily produce internal tibial torques as high as 99 Nm without injury (Shoemaker, 1988). The tibia is able to withstand approximately 115 Nm before failure while the average torque for ankle injury is approximately 70 Nm (Hirsch and Lewis, 1965). Thus, the knee joint is the weak link in the lower leg for torsion related injuries and this may account for the relatively high rates of ACL injuries in athletes.

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