Knee Kinematics During Non-contact ACL Injury As Determined From Location Of Bone Bruises

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Disclosures:

Introduction: Over 200,000 anterior cruciate ligament (ACL) injuries occur annually in the U.S. [1], with non-contact injuries accounting for 70% of these tears [1]. Regardless of treatment, ACL-injured individuals frequently experience meniscal tears, knee pain, and early onset osteoarthritis [2]. In an effort to prevent non-contact ACL injuries, much effort has been devoted to neuromuscular training programs. However, these prevention programs have shown varying results and ACL injury rates remain high [3]. This may be due to a lack of data describing which motions are high-risk for ACL injury. After ACL injury, bone bruises are commonly visible on magnetic resonance (MR) images of the knee. These contusions are thought to be indicative of impact occurring between the femur and tibia near the time of ACL injury [4]. Although researchers have studied the frequency and location of these bone bruises [4], there is a lack of data quantifying the position of the knee at the time of injury. Thus, the objective of this study was to determine the relative position and orientation of the knee near the time of ACL injury by using MR imaging, 3D modeling, and numerical optimization techniques to maximize the overlap of the surfaces of the bone bruises on the femur and tibia.

Methods: Eight ACL-injured subjects (average age 23 ± 5 years, 5 males and 3 females) were included in this retrospective study. All subjects had experienced a non-contact ACL rupture within one month of MR imaging. Sagittal FSE T2-weighted MR images with a slice thickness of 3-4 mm, a matrix of 256x256 interpolated to 512x512 pixels, TR of 3000ms, and TE of 70ms were reviewed and analyzed for this study. Six subjects had Grade 1 MCL tears, while the remaining two subjects had no evidence of MCL injury. Four subjects had no evidence of a tear or abnormal MR signal in their menisci, and the remaining four subjects had small tears to their medial or lateral menisci. Bone bruises were visible in both the medial and lateral compartments of the femur and tibia for all subjects. Using these MR images, the cortical bone and bone bruise surfaces were outlined using 3D modeling software (Rhinoceros, McNeel and Associates, Seattle, WA). The outlines were combined to form a 3D model of the knee and bone bruises (Figure 1).

Numerical optimization was then used to maximize the overlap of the surfaces of the bone bruises on both the femur and tibia. Specifically, the optimization algorithm, written in Mathematica (Wolfram, Champaign, IL), rigidly translated and rotated the relative position of the femur and tibia such that the distance between points evenly distributed across the surfaces of the bone bruises were minimized. The optimization was constrained to minimize penetration of the boney surfaces. The relative position of the femur and tibia were measured before and after optimization using anatomic coordinate systems previously described in the literature [5]. Specifically, flexion, valgus, internal rotation of the tibia, and anterior tibial translation were measured. Differences in kinematics between the initial position during MR imaging and after the optimization were compared using a paired t-test. Differences were considered statistically significant where p < 0.05.

Results: Flexion did not change significantly between the initial and optimized positions (p = 0.3). However, statistically significant increases in anterior translation (22mm, p < 0.001), internal rotation (17°, p = 0.002), and valgus orientation (5°, p =0.003) were observed.

Discussion: Despite implementation of prevention programs, rates of non-contact ACL injury remain high. The efficacy of prevention programs is likely hindered by an unclear understanding of what motions lead to an ACL injury [1]. This study used numerical optimization and the geometry of the bone bruises on the femur and tibia to provide a measurement of the position of the knee near the time of ACL rupture. The large anterior shift (22mm) of the tibia relative to the femur and slight valgus orientation (5°) was consistent with the kinematics measured in a previous cadaveric model employing an aggressive quadriceps load to rupture the ACL [6]. Furthermore, the position of the knee in low flexion (12°) was consistent with previous in vivo studies indicating that ACL strains are maximal when flexion is minimal [7], a position when the quadriceps can load the ACL due to the anterior pull of the patellar tendon on the tibia [8]. These data suggest that landing on a straight knee may be a high risk position for ACL injury. These findings are important because understanding what movement patterns elevate ACL injury risk is crucial to the prevention of this devastating injury.

Significance: This study provides important information regarding the position of the knee near the time of ACL injury. These findings are significant because an improved understanding of the motions leading to ACL rupture is essential to improving the efficacy of neuromuscular training programs aimed at ACL prevention.

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Figure 1: 3D models of the initial (left) and optimized (right) position of the knee in the sagittal view. Femoral condyle bruises (red) overlap with the tibial plateau bruises (blue) in the optimized position.

Figure 2: Average (A) flexion, (B) valgus, (C) internal rotation of the tibia, and (D) anterior translation of the tibia in the initial and optimized positions. (*p<0.05)

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