KNEE ARTICULAR CARTILAGE PRESSURE DISTRIBUTION UNDER SINGLE- AND MULTI-AXIS LOADING CONDITIONS: IMPLICATIONS FOR ACL INJURY MECHANISM

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INTRODUCTION
Acute anterior cruciate ligament (ACL) injury is one of the most common and devastating knee injuries, which is often associated with bony contusions of the lateral tibial plateau [1]. Previous studies have shown that abduction and internal rotation moments are critical factors in the mechanism of ACL injury [2]. The purpose of this study was to determine the effects of abduction and internal rotation moments on the pressure distribution of the tibiofemoral lateral compartment under single- and multi-axis loading conditions. We hypothesized that there is a relationship between intra-articular pressure distribution patterns and the mechanism of loading the ACL under injurious conditions. This relationship may enhance our knowledge of ACL injury mechanisms. Such insight could improve current prevention strategies designed to reduce the risk of ACL injury and damage to secondary structures acting to decrease associated posttraumatic knee osteoarthritis.

METHODS
16 fresh frozen cadaveric lower limbs (45±7 years, 8 females and 8 males) were sectioned at the mid-shaft of the femur and potted in polyester resin. The quadriceps (rectus femoris) and hamstrings (semitendinosus, biceps femoris and semimembranosus) tendons were isolated and sutured inside metal tendon grips for the application of simulated muscle forces. Specimens were tested using a custom designed passive six-degree of freedom Force Couple Testing System (FCTS). This system utilizes servo-electric actuators to drive a cable-pulley system that generates an unconstrained pure moment from full extension through 90˚ of flexion. A K-Scan sensor (Tekscan Inc, Boston, MA) was used to map tibiofemoral articular pressure distribution. This system allows for the bicondylar tracking of pressure distribution with high resolution (0.1 MPa and 0.1 mm). Prior to use, each sensor was laminated, then equilibrated and calibrated based on manufacturer recommendations. With the anterior horn of the medial and lateral meniscus dissected from the tibial plateau, the sensor was arthroscopically placed into the medial and lateral compartments below the menisci. Care was taken to avoid crinkling of the sensors, while sensors were sutured to the knee capsule to avoid relative translations. An external fixation frame was attached to the tibia such that the centers of the pulleys were located about the knee center of rotation. External loads were applied to specimens using a combination of static weights and cable-pulley systems through the external fixation frame.
Simulated muscle forces (400 N quadriceps and 200 N hamstrings) were used as a baseline. The following loading conditions were applied to each specimen in addition to the baseline, while the specimens were cycled from 0˚ to 90˚ of flexion: 5, 10 and 15 Nm of pure abduction, 5, 10 and 15 Nm of pure internal rotation, 15 Nm abduction + 5 Nm internal rotation and 15 Nm abduction + 10 Nm internal rotation.
Data were analyzed using Analysis of Variance (ANOVA) with a post-hoc Bonferroni Correction for multiple comparisons and general linear model (GLM) to investigate the effects of each loading parameters on articular pressure distribution. Differences were considered statistically significant for p<0.05.
RESULTS AND DISCUSSION
Increased abduction and internal rotation produced higher intra-articular peak pressure (Figure 1). While higher internal rotation moved the location of the center of pressure (COP) in the anterior-posterior (A-P) direction (Figure 2), no significant medial-lateral (M-L) translation of the COP was observed under simulated loading conditions (Figure 3). At 25° of flexion, 15 Nm of Abduction significantly increased intra-articular peak pressure in the lateral compartment from 6.0±3.5 MPa to 9.1±2.6 MPa (P<0.0005), while the COP was not affected. 15 Nm of internal rotation increased intra-articular peak pressure in the lateral compartment to 6.5±3.2 MPa and moved the COP by 1.6±0.7 mm posteriorly. Combined 15 Nm abduction and 10 Nm internal rotation generated the highest intra-articular peak pressure (9.7±1.8 MPa, P=0.002).

The GLM demonstrated that internal rotation significantly affects A-P translation of COP in the lateral compartment (p=0.03). Further, abduction moment significantly increase intra-articular peak pressure across the knee lateral compartment (p<0.0005). The combination of abduction and internal rotation moments increased the intra-articular peak pressure, while translating the COP posteriorly. However this amount of COP translation was not substantial, which could be due to low magnitudes of applied axial rotation moments. Further, data suggested that the lateral COP will move to its most posterior location between 15-30° of knee flexion and coming back toward the initial position an again translating posteriorly in deep flexion under all modes of loading except pure internal rotation. No substantial A-P translation of the COP was observed after the first peak posterior translation under pure internal rotation. This peak posterior translation of the COP at low knee flexion angles can be an indication of the ‘screw-home’ mechanism.

CONCLUSIONS
To the author’s knowledge, this is the first time that knee intra-articular pressure distribution has been investigated under single- and multi-axis loading conditions over a range of flexion. Relatively low magnitudes of external loads were used in this study to avoid structural damage to both soft and boney tissues. Our findings support our hypothesis that there is a relationship between intra-articular pressure distribution patterns and knee loading mechanisms in a way that abduction will cause high pressure concentration in the mid-lateral tibial plateau while internal rotation will cause high pressure across the postereolateral tibial plateau.

REFERENCES

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