Impacts of MCL and Medial Meniscus Injuries on Ovine Knee Kinematics after Healing

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Disclosures:

Introduction: Functional demands placed on the human anterior cruciate ligament (ACL) vary with activity but remain impossible to measure directly in vivo. Our lab is characterizing these demands in the sheep model by recording in vivo knee kinematics and ACL transducer voltages during activities of daily living (ADLs), reproducing these motions using the instrumented limb, and measuring the three-dimensional (3D) forces in the ligament to identify criteria for repair. In addition to reconstruction demands for patients sustaining an isolated ACL injury, demands have yet to be quantified for the 13% of patients who also sustain a dual medial meniscus (MM) injury, or the 10% who sustain a dual medial collateral ligament (MCL) injury [1]. These structures are frequently left unrepaird, which may alter knee kinematics and the ACL’s functional demands, resulting in inadequate ACL reconstruction outcomes for patients with dual injuries. Although these structures have been shown to alter ACL loading in cadaveric studies [2-3], the extent to which they impact ACL functionality during in vivo ADLs remains unknown. Moreover, changes in ACL functionality and knee kinematics over time due to joint healing and remodeling have yet to be investigated. This study aimed to record changes in 3D knee kinematics resulting from the injury and natural healing of the MM and MCL. Results of this study will be used in conjunction with future robotic studies to estimate in vivo load requirements for ACL reconstructions in patients with dual injuries.

Methods: Twelve (12) skeletally mature, female Suffolk sheep (age: 2-6 yrs; weight: 100-200 lbs) were used in this IACUC approved study. Animals walked at one speed (1 m/s) during level (0°), inclined (+6°), and declined (-6°) conditions using an instrumented treadmill (Kistler Gaitway, Amherst, NY). After at least three weeks of training, one co-author (MG or SH) surgically exposed the medial aspect of the left hind limb to perform an MCL, MM, or dual injury. MCL injuries were imposed by removing a 1cm section of the ligament spanning the joint line. MM injuries were imposed by removing the MM in its entirety by detaching the anterior and posterior horns. Post-injury animals walked on the treadmill twice weekly for 12 weeks of healing during which the animals were allowed to move freely. The surgeon fixed electro-magnetic trackers (Polhemus Liberty, Colchester, VT) antero-medially to the proximal tibia and distal femur. An arthroscopically implantable force probe (AIFP, Microstrain, Burlington, VT) was also implanted into the midsubstance of the ACL to monitor ligament strains for future kinetic analysis. Lead wires were run subcutaneously to the gluteus maximus and then to the left side of the abdomen where the connectors exited the body. Gait kinematics were recorded for all inclinations at 2, 6, and 9 days post-surgery. All data for each animal were normalized over a full gait cycle with respect to hoof strike, using at least 5 consecutive strides. A Welch two sample t-test was then used to determine statistical significance of the results.

Results: Following twelve weeks of recovery, anterior/posterior kinematics of MM-injured animals (N=3) demonstrated increased anterior translation during stance phase, while MCL-injured animals (N=4) demonstrated increased posterior translation during swing phase compared to normal animals (N=4). The average anterior translation of MM injured sheep (1.58 ± 0.53mm at level) was significantly higher than of MCL injured sheep (0.28 ± 0.25mm at level, p < 0.01) for all inclinations and approached significance compared to normal in the declined condition (data not shown, p=0.07). The dual-injured animal’s (N=1) anterior/posterior translation combined both the MM and MCL-injured groups (Fig 1. A).

In addition, average compression value of MM-injured animals during stance phase (1.19 ± 0.67mm at level) was significantly higher than normal sheep (-0.14 ± 0.95mm at level) for both inclined and declined conditions (data not shown, p<0.05) and approached significance for the level condition (Fig 1. B, p=0.07). MM-injured animals also demonstrated significantly lower levels of maximum distraction (-1.03 ± 0.29mm at level) compared to normal (-2.58 ± 0.91mm at level) and MCL injured animals (-2.62 ± 0.75mm at level) during swing for all inclinations (Fig 1. B, swing, p<0.05). The dual-injured animal demonstrated compression/distraction kinematics more in line with MCL-injured animals (Fig 1. B).

Discussion: As expected, kinematic results of the MM-injured animals showed higher levels of anterior translation and compression during stance phase, as the MM has been shown previously to play primary restraining roles in these degrees of freedom [3]. MM-injured animals also experienced lower levels of posterior translation and distraction during swing, which may be explained by a stiffening of the knee as it remodeled during the 12 weeks of healing. Differences in MCL-injured animals showed less significant kinematic changes than expected. Interestingly, kinematics of the dual-injured animal appeared to be more aligned with the MCL injury than the MM injury, particularly in compression/distraction, though kinematic data is only available for one dual-injured animal at this time.
We theorize that the MCL injury may have counteracted the MM injury in the dual-injured animal, leading to normal compression/distraction kinematics during the stance phase of gait. Sheep knees are naturally abducted throughout gait, potentially emphasizing the role of the MCL even during stance phase. However, a proprioceptive feedback mechanism may be at work. Previous studies have shown that, in response to unilateral MCL injury, vertical ground reaction forces (VGRFs) are altered in both hind limbs, while MM injury only affects VGRFs of the injured limb [4]. Future studies will use our robotic testing platform to reproduce kinematics for each test subject, measuring the corresponding kinetics in response to MM, MCL, and dual injuries. This analysis will help to identify the mechanisms responsible for kinematic changes in response to the healing of traumatic knee injuries.

**Significance:** Current ACL reconstruction techniques remain ineffective in avoiding or delaying the onset of osteoarthritis, implicating a failure to restore native ACL function and knee kinematics [5]. This research is designed to establish ACL reconstruction design criteria following combined injury to the MCL or MM aimed at: 1) accelerating patient return to pre-injury activities and 2) slowing or stopping premature joint degeneration.

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**Figure 1.** A. MM injury led to increased anterior translation in stance, while MCL injury led to increased posterior translation in swing. Dual injury showed both effects. B. MM injury led to higher compression values during stance. Dual injury values were comparable to normal and MCL-injured animals.