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IN VIVO LIGAMENT AND MENISCAL LOADS FOLLOWING ACL INJURY: A LONGITUDINAL STUDY

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SUMMARY

The in vivo mechanics of the ovine stifle joint were studied longitudinally following anterior cruciate ligament (ACL) transection. We aimed to determine how ACL deficiency would alter the normal mechanical environment of the joint, both short and longer term, in vivo.

INTRODUCTION

Severe injuries to the ACL can lead to the development of osteoarthritis (OA) [1]. This may be due to altered mechanics (e.g.: chronic instability), altered biology (e.g.: inflammation), or a combination of both factors [2]. The main objective of the present study was to investigate the in vivo mechanics of the ovine stifle joint over time following ACL injury. The ovine stifle joint is a promising biomechanical model of human knee joint. Following injury sheep develop OA at a slightly accelerated rate compared to humans but with some similar patterns [3]. We aimed to see how ACL deficiency alters the loads borne by different tissues within the knee joint (cruciate ligaments, collateral ligaments, and menisci) over time, in vivo.

METHODS

Five skeletally mature (N=5) female Suffolk-cross sheep (average weight 80±6 kg) had a bone plate implanted onto each of the proximolateral aspect of the tibia and the distolateral aspect of the femur of their hind limbs, four weeks prior to kinematic testing. On the day of kinematic testing, a 12.7 mm diameter stainless steel post was attached to each plate and an instrumented spatial linkage (ISL) mounted between them. The ISL consisted of six rotational encoders providing six degrees of freedom (6-DOF) to its motion. The 6-DOF in vivo kinematics of the stifle joint was measured during “normal gait” while the sheep walked on a treadmill at 2 mph (0.89 m/s). Each sheep then underwent an arthroscopic stifle surgery in which their ACL was fully transected. The in vivo gait kinematics was measured again over time, at 4 weeks and 20 weeks time points following ACL injury (Figure 1). Following kinematic testing at 20 weeks, the animals were euthanized by intravenous injection and their hind limbs were disarticulated. All surrounding tissue was removed from the joint, sparing the collateral and cruciate ligaments, and the menisci. All animal surgeries and testing were approved by the University of Calgary Animal Care Committee and comply with the guidelines of the Canadian Council on Animal Care.

A coordinate measuring machine was used to measure anatomic landmarks with respect to the ISL in order to create an anatomically relevant coordinate system. Each joint was then mounted on a unique 6-DOF parallel robot (R-2000, PRSCo, Hampton, NH, USA; 0.05 mm accuracy). The tibia was fixed rigidly to a tibial fixture system, while the femur was clamped to the robot end-effector. The robot was programmed to move the femur relative to the tibia through all the previously recorded in vivo gait paths (normal, 4 weeks, and 20 weeks kinematics), using real-time feedback data from the ISL to the robot control system [4]. In this way, the in vivo motions were reproduced to within 0.1 mm and 0.1 deg using the robotic test system. The in vivo gait loads were simultaneously recorded using a universal force/moment sensor, and the load borne by each tissue (collateral ligaments, cruciate ligaments, and menisci) was determined using the principle of superposition.

RESULTS AND DISCUSSION

The loads carried by each tissue as a function of the proportion of gait cycle are represented in Figures 2-6, where a gait cycle is defined from one hoof strike to the next. Colored lines represent the mean of the unique strides measured for each animal, and the shaded areas denote +/- 1 standard deviation for 15 strides.

Our results indicate significant inter-subject variability in tissue loads and tissue adaptations following ACL injury, as in humans. The medial and lateral collateral ligament (MCL and LCL) forces increased considerably short-term (4 weeks) following ACL injury but returned to within normal ranges, or are decreased dramatically compared to normal conditions for some subjects, in the longer term (20 weeks). The in vivo MCL and LCL loads before and after ACL injury are presented in Figures 2-3 for one of the subjects.

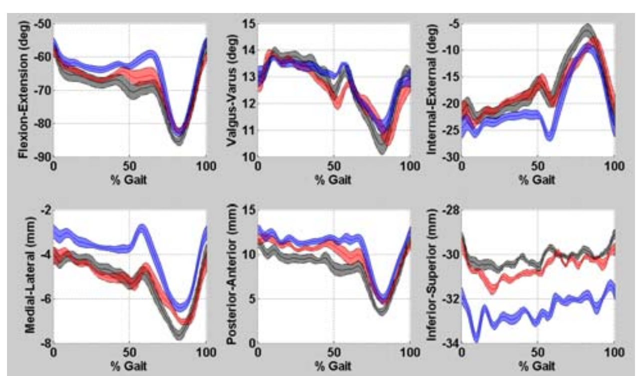

Figure 1: The 6-DOF in vivo kinematics of the ovine stifle joint during gait, before (black), short-term (4 weeks) after (red), and long-term (20 weeks) after (blue) ACL transection (subject #2)

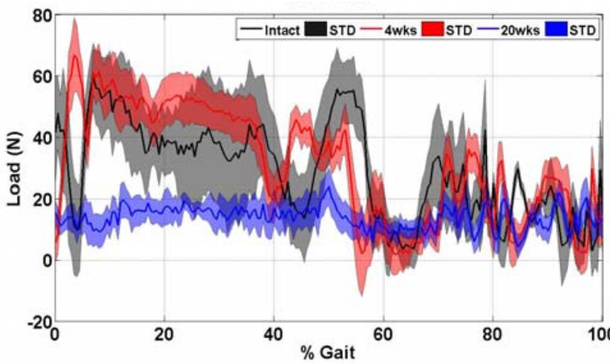

Figure 2: In vivo MCL load during gait before, short-term after, and long-term after ACL injury (subject #2)

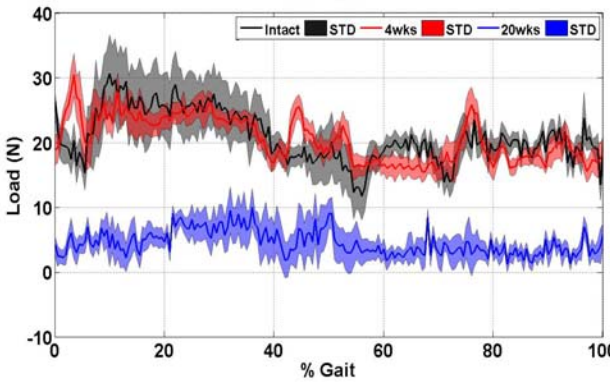

Figure 3: In vivo LCL load during gait before, short-term after, and long-term after ACL injury (subject #2)

The posterior cruciate ligament (PCL) behavior was also quite variable between different subjects. For some subjects the PCL forces decreased following ACL injury and continued to decrease over time; whereas, for other subjects PCL forces increased remarkably following ACL injury and did not return to normal ranges in the longer term. The in vivo load borne by PCL during gait for one subject (subject #2) before and after ACL injury is illustrated in Figure 4.

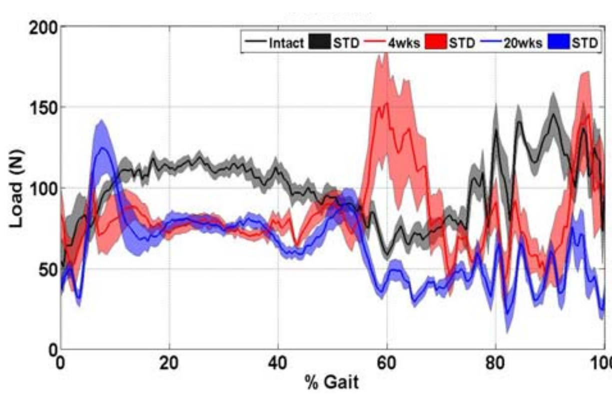

Figure 4: In vivo PCL load during gait before, short-term after, and long-term after ACL injury (subject #2)

In contrast to collateral and cruciate ligaments, the meniscal adaptations were quite similar between subjects following ACL injury. All subjects demonstrated a dramatic increase in meniscal loads, both short and long term, compared to normal conditions (Figures 5-6).

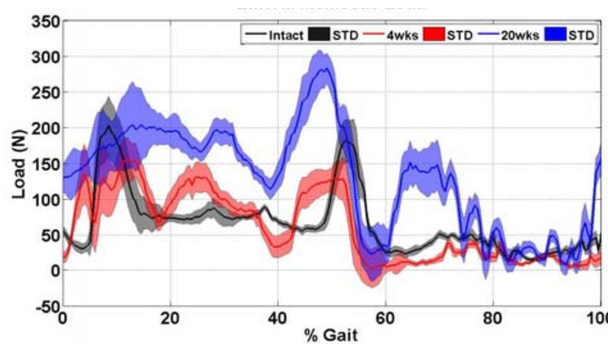

Figure 5: In vivo Lateral Meniscus load during gait before, short-term after, and long-term after ACL injury (subject #2)

For some subjects, the meniscal loads doubled or even tripled following injury. This would imply that the menisci play a significant role in helping stabilize the knee following ACL injury [5] and may explain the meniscal failures often reported following chronic ACL deficiency.

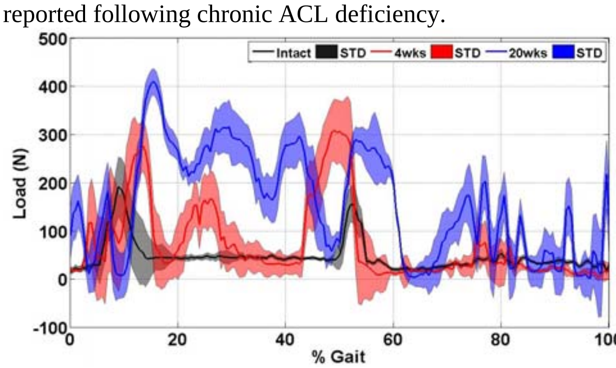

Figure 6: In vivo Medial Meniscus load during gait before, short-term after, and long-term after ACL injury (subject #2)

CONCLUSIONS

The normal mechanical environment of the ovine stifle joint was established by quantifying the in vivo loads borne by all major ligaments and the menisci during normal gait. This normal environment is altered in varied ways following ACL injury, both in the short and longer terms. Large inter-subject variability was observed in tissue loads and tissue adaptations following ACL injury. The menisci also appeared to play a vital role in helping the animals provide stability to their knee joint following ACL injury, perhaps by further constraining anterior tibial loads or resisting increased muscle contraction forces on the joint. This is the first in vivo study quantifying the mechanical load redistribution in various key tissues in the joint following ACL injury over time. Our next step will be to study the corresponding biological changes in these joints in an attempt to determine cause and effect relationships with respect to developing post-traumatic OA.

ACKNOWLEDGEMENTS

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REFERENCES

1. Andriacchi TP, *Nat Rev Rheumatol.* **8**:371-372, 2012.
2. Lohmander LS, et al., *Am J Sport Med.* **35**:1756-1769, 2007.
3. Frank CB, et al., *J Orthop Res.* **30**:384-392, 2012.
4. Atarod M, et al., *Knee.* **19**:797-803, 2012.
5. Woo SL, et al., *J Orthop Res.* **18**:109-115, 2000.