Design and Evaluation of Instrumentation used for Lateral Tibia Impacts

Matt Kremer[1], Rod Herriott[2], Ann Mallory[2], John Bolte IV[1]

[1]The Ohio State University, [2]Transportation Research Center

Background

- Non-fatal pedestrian-vehicle collisions involved 61,000 pedestrians in 2006 [1]. Thirty percent of all injuries incurred by pedestrians involved in this type of collision are to the lower extremities, many of which are to knee ligaments [2].
- Knee injuries are also among the most economically costly sports injuries and are the leading cause of high school sports-related surgeries (nearly 45%). These injuries can require extensive and expensive post-surgery rehabilitation and can increase risk for early onset osteoarthritis [3].
- The medial collateral ligament (MCL) and anterior cruciate ligament (ACL) are often injured under lateral loading conditions.
- The Injury Biomechanics Research Laboratory (IBRL) previously developed instrumentation for anterior tibia impacts, including instrumentation to measure posterior cruciate ligament (PCL) stretch.
- The goals of this research are to expand on methods from anterior impacts to develop an instrumentation technique for lateral knee impacts, focusing specifically on MCL and ACL stretch and injury.

Objectives

- **Accurately measure tibial angular rotation relative to the femur**
- **Accurately measure ACL and MCL stretch**
- **Identify the time of injury for ligament and bone failure**

Methods

- Four denuded legs from 3 Post-Mortem Human Subjects (PMHS) were used in this study.
- Accelerometers and angular rate sensors were installed on a 3a**ω** motion block (Fig 1) and attached to the tibial tuberosity (Fig 2). These were used to determine angular velocity and the angle of the tibia with respect to the femur during loading.
- Micro-differential variable reluctance transducers (Micro-DVRTs) were inserted into the ACL and MCL (Fig 3) to measure stretch of the ligaments.
- Legs were positioned and released at different heights resulting in increasing impact energy. The thigh interacted with an impact plate, causing loading about the knee (Fig 4). Baseline trials at a height of 4 inches were performed between each height increase to test for injury.

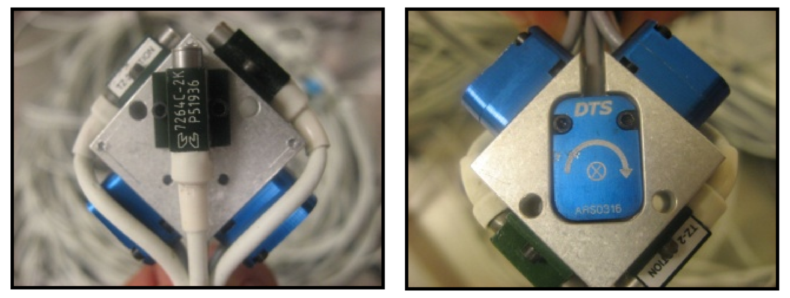

Figure 1. 3aω motion block with accelerometers and Angular Rate Sensors (ARS)

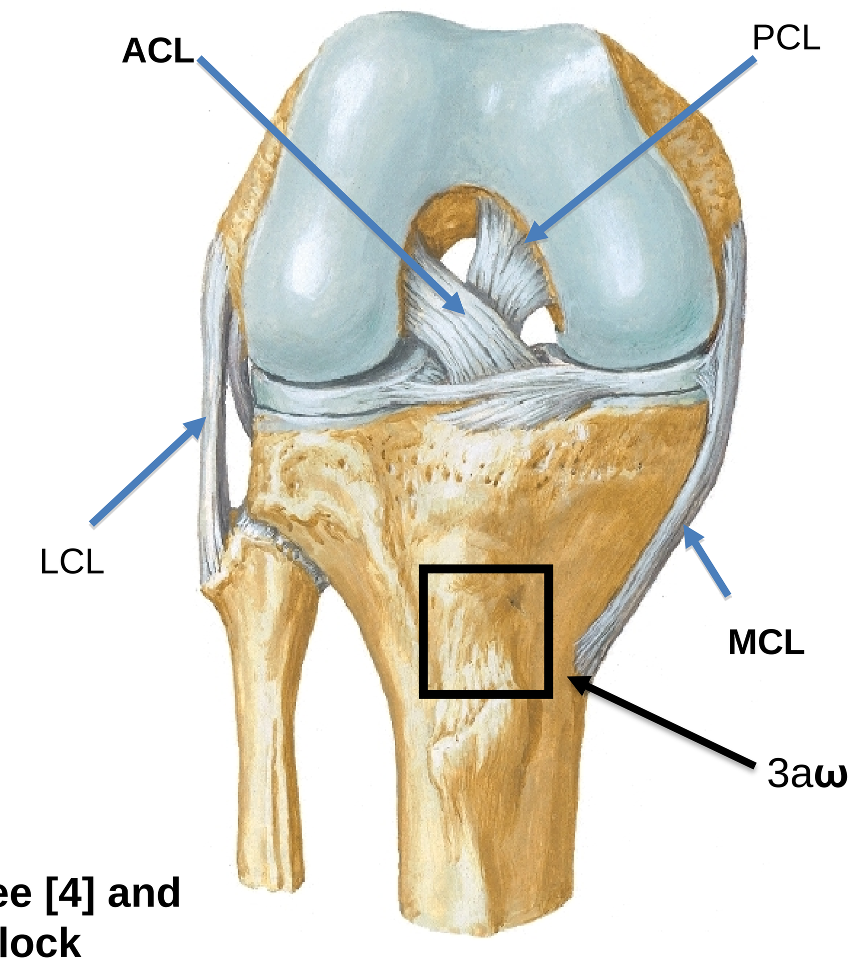

Figure 2. Ligaments of the knee [4] and location of 3aω motion block

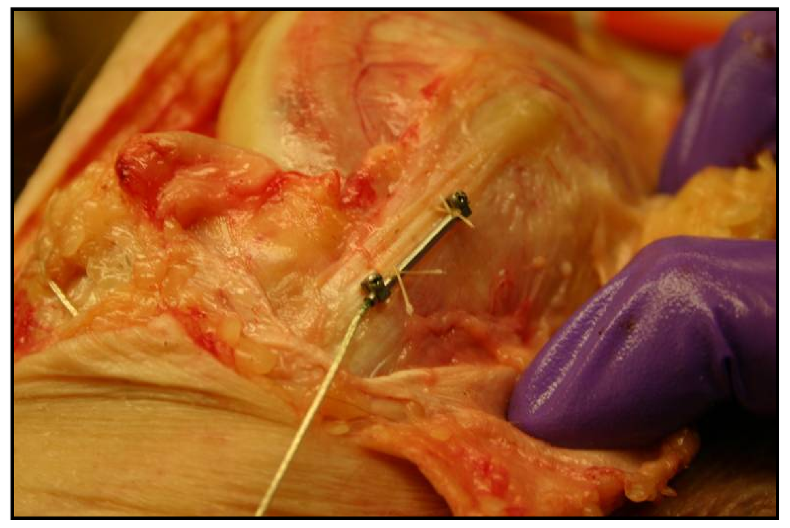

Figure 3. Micro-DVRT installed in MCL

Table 1. Summary of Measurement Variables and Devices

Measured Value	Measurement Device
Tibia Motion	Integrated Accelerometers
Femur Motion	Integrated Accelerometers
Femur Force	Six Axis Load Cell
Force at Impact Location	Six Axis Load Cell
MCL Stretch	Micro-DVRT
ACL Stretch	Micro-DVRT

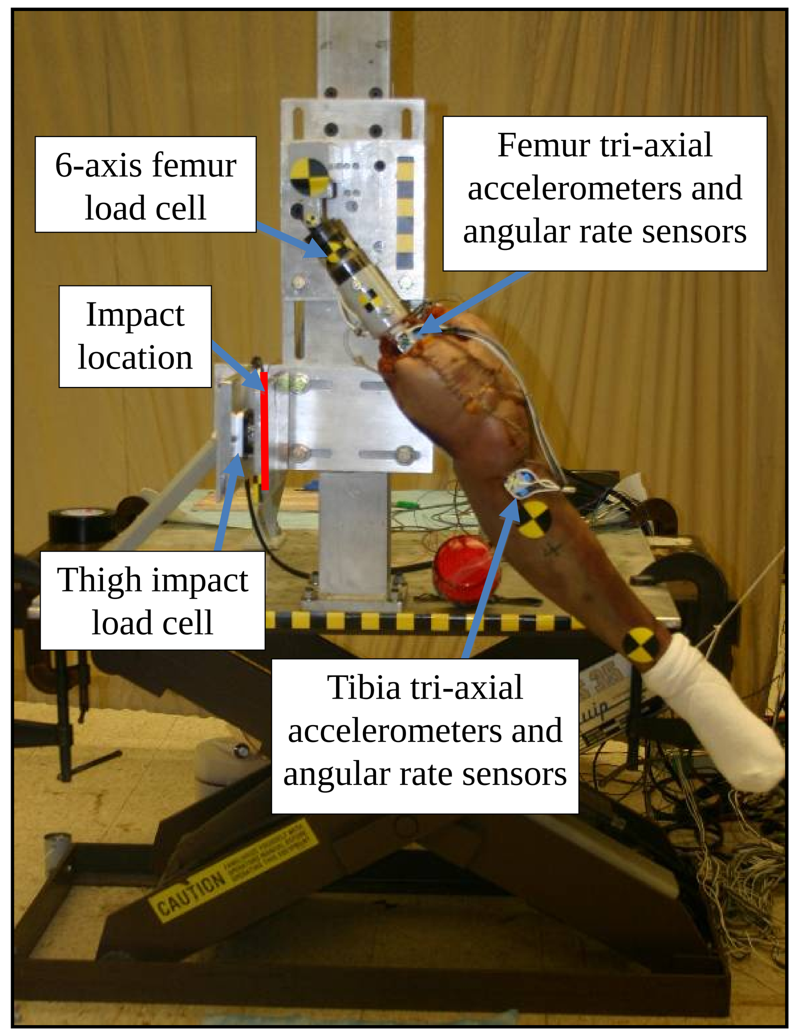

Figure 4. PMHS Test Setup

Results & Discussion

- Findings are consistent between all 4 legs tested. Results from Subject 1 are summarized here.
- ACL injury occurred to the right leg at a height of 19 inches (0901PED19R09) (Fig 5). Time of injury was determined by using both MCL and ACL data (Fig 7).
- Injury was verified by the following baseline impact (0901PED04R10) in which the response was much different than that of all of the previous baseline tests (Fig 5).
- An additional trial (0901PED19WR11) was conducted in which a 5 lb weight was added to the sole of the shoe. Complete tearing of the ACL from the femur occurred as a result. This was confirmed by baseline impact (0901PED04R12).

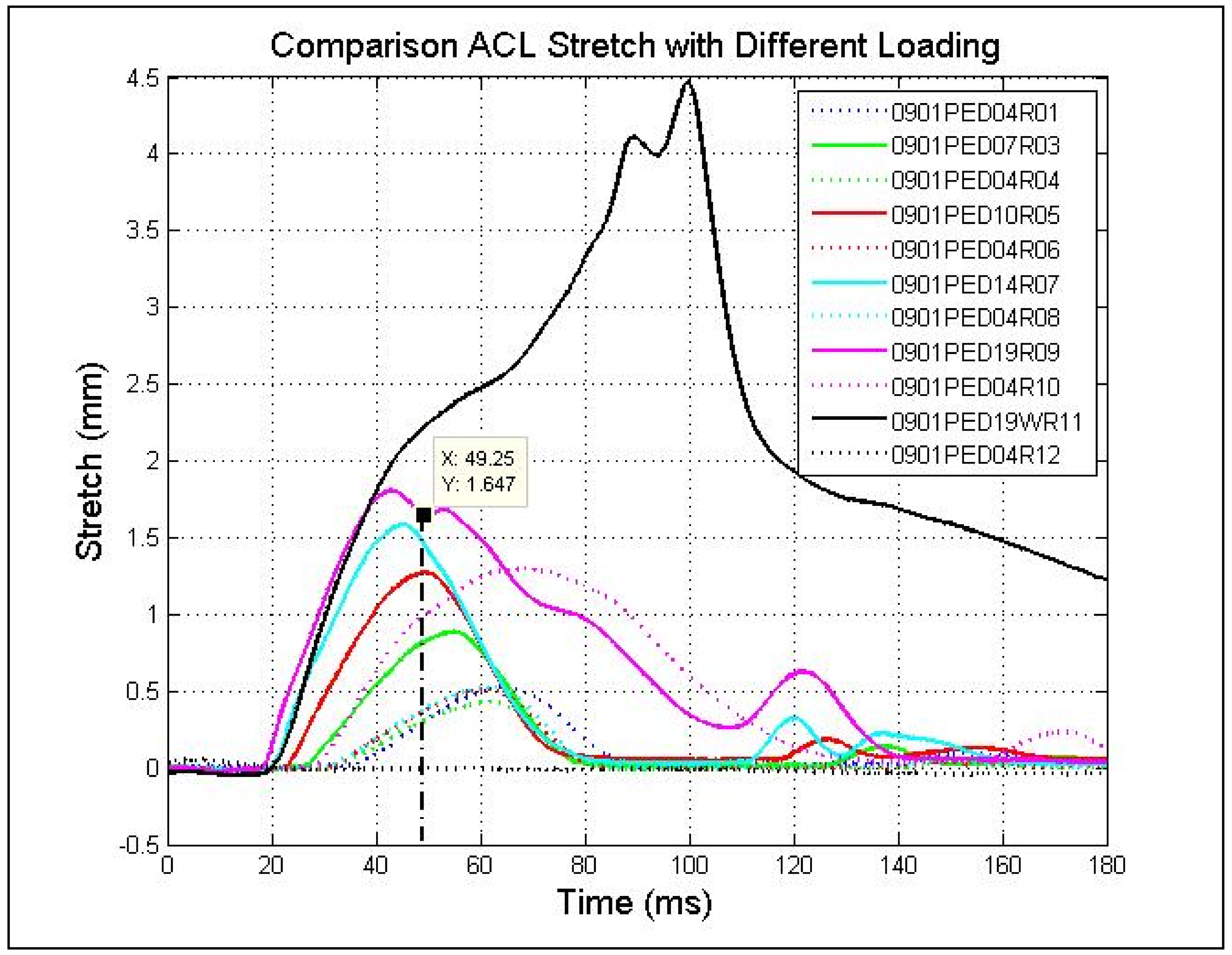

Figure 5. ACL Response at different impact heights with time of injury labeled. Colors represent different impact heights and dotted lines represent corresponding baseline trials.

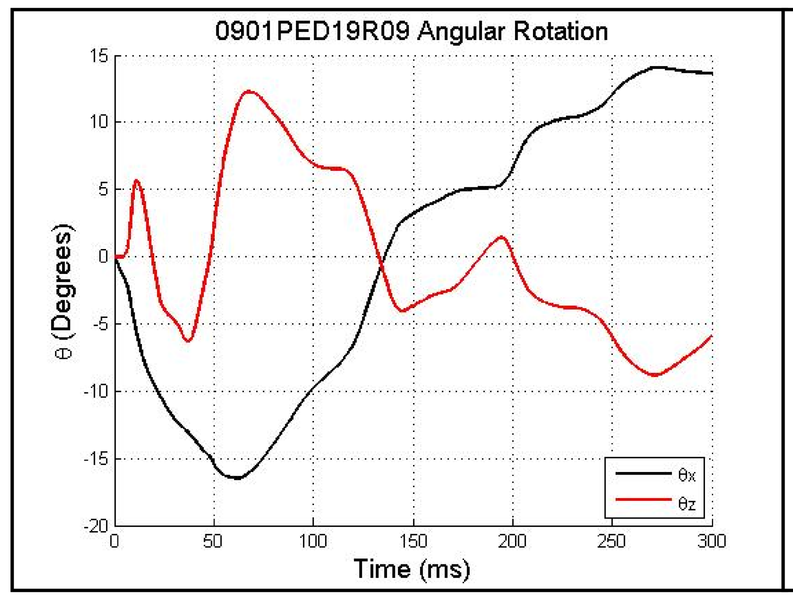

Figure 6. Angular rotation (θ_x) and twist (θ_z) of the knee seen during injury trial

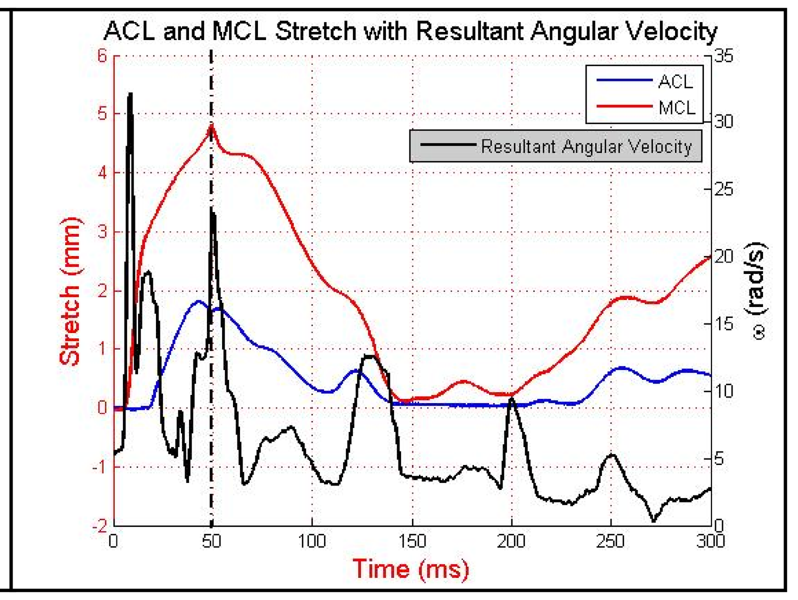

Figure 7. ACL and MCL stretch with resultant angular velocity. Dashed line indicates time of injury.

- A considerable amount of rotation (**θ**x) and twist (**θ**z) occurs at the knee during lateral impact, approximately -17˚ and 13˚ respectively (Fig 6).
- The combination of bending and twisting causes injury to the ACL.
- By plotting ACL and MCL stretch with the resultant angular velocity at the knee, it can be seen that at time of injury there is also a spike in angular velocity. This suggests that angular velocity may be able to accurately predict injury (Fig 7). Future work should include additional trials to support this hypothesis.

Table 2. Summary of Injuries

Subject #	Leg	Impact Height (in)	Time of Injury (ms)	Injury
1	Right	19	49.25	Tearing of ACL fibers begin
1	Right	19 with 5 lb weight	N/A	ACL torn off femur-Not Avulsion but a pure tear of 75% of the fibers. Small avulsion of medial tibial plateau
2	Right	19 with 2.5 lb weight	62.25	MCL- approx. 1/3 of fibers torn ACL- partial tear of approx. 10% of fibers
2	Left	19 with 2.5 lb weight	57.6	ACL- approx. 20-25% of ligament avulsed from femur
3	Right	19 with 2.5 lb weight	N/A	No ligament injury found. Knee laxity was caused by prior dissection of thigh muscles

Conclusions

- **Securely suturing DVRT barbs to the ACL and MCL provide repeatable displacement measurements.**
- **Time of injury can be accurately determined with both MCL and ACL DVRT signals.**
- **Angular velocity may be able to accurately predict injury.**

References

[1] Mallory A., Stammen J.,National Highway Traffic Safety Administration, 'Traffic Safety Facts 2006-Pedestrians', DOT HS 810 810.
[2] van Dommelen JA, Jolandan MM, Invarsson BJ, Millington SA, Raut M, Kerrigan JR, Crandall JR, Diduch DR. (2005). Pedestrian injuries: viscoelastic properties of human knee ligaments at high loading rates. Traffic Injury Prevention. 6(3): 278-87.
[3]The American Journal of Sports Medicine. June 2008.
[4] The Netter Presenter: Human Anatomy Collection Version 2.0, Icon Learning System, LLC, Teterboro, NJ