Altered Tibiofemoral Motion and ACL Strain During Knee Flexion Against Simulated Eccentric Quadriceps Forces

Drew Warnick, MD ; Jeremy Goodsitt, ; Mark Sartori, BS ; Josh Snyder, MD ;
Robert M. Havey BS ; Pietro Tonino, MD; Avinash G. Patwardhan, PhD; **Steven Chudik, MD**
OTRF, Musculoskeletal Biomechanics Laboratory, Hines Va, Loyola University Medical Center, Hinsdale Orthopaedics

Introduction

Lesser knee flexion angles and large eccentric quadriceps forces have been implicated in the mechanism of non-contact ACL injuries.

Hypothesis

Forced early knee flexion against an active eccentric quadriceps contraction will alter tibiofemoral motion and increase strain in the ACL.

Study Design

Biomechanical cadaveric laboratory study using a customized optoelectronic motion analysis system.

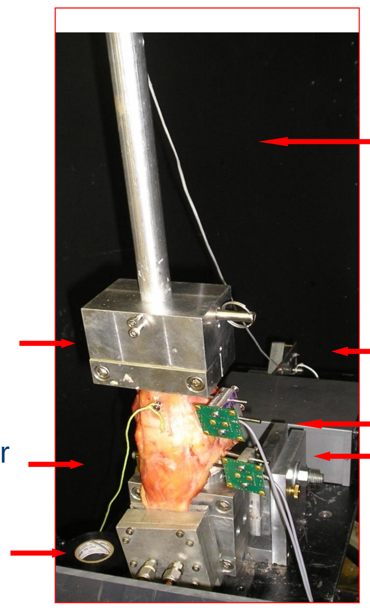

Fig. 1) Testing fixture

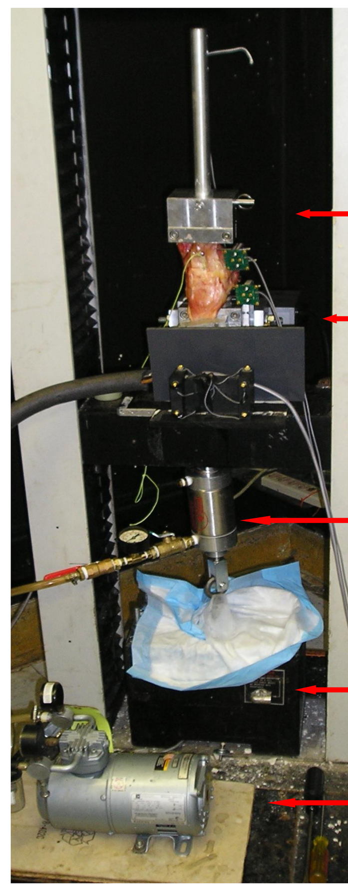

Fig. 2) Testing set-up

Materials & Methods

- 5 cadaveric knee specimens (mean age 58 ± 16.7) were inverted and cemented into a fixture to allow slow knee motion from full extension to 40 degrees of flexion. **(Fig. 1)**
- The quadriceps tendon was placed in a cryoclamp and connected to an Instron machine by a polyethylene cord in series with an air cylinder. **(Fig. 2)**
- The knee was flexed by a motor connected with a polyethylene cord to the tibial side of the specimen fixture. Knee flexion against the quadriceps force generated by the instron machine in series with the air cylinder simulated a physiologic eccentric force.
- The cylinder was pressurized with air to different levels (0,10,20,30 psi) to create increasing eccentric quadriceps forces ranging from 200 N to 3000 N. **(Fig. 3)**
- Tibiofemoral motion was analyzed during flexion using a three-dimensional customized optoelectronic tracking system with targets rigidly attached to the tibia and femur. **(Fig. 1)**
- Sequential screw axis parameters of the intact knee joint were determined for the different quadriceps forces applied during flexion. **(Fig. 4)**
- After testing, the knee was dissected and a optoelectronic sensor probe was used to systematically map the joint surfaces and the insertion and origin of the individual bundles of the ACL, all in reference

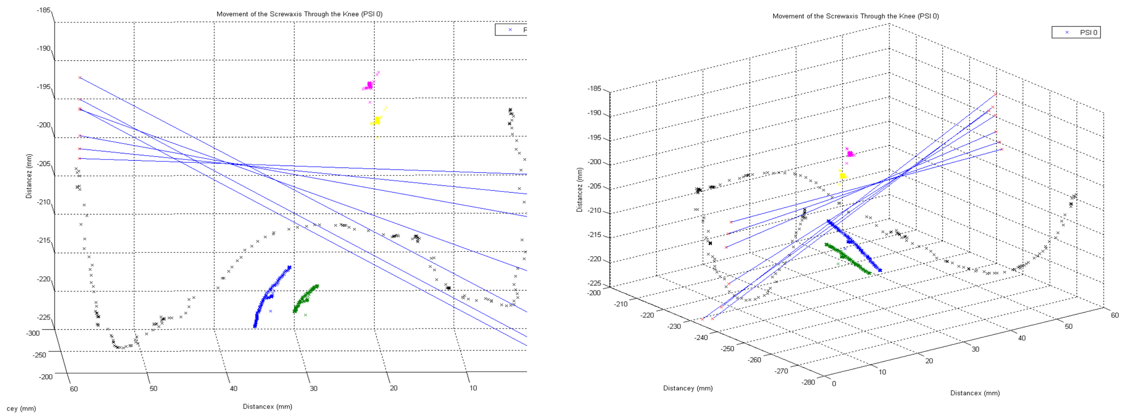

Fig. 4) AP and oblique view of one set of screw axis parameters. Black- femoral condyles, Pink-AM origin, Yellow-PL origin, Blue-AM insertion, Green- PL insertion, Blue lines represent screw axes for every 7 deg. of flexion

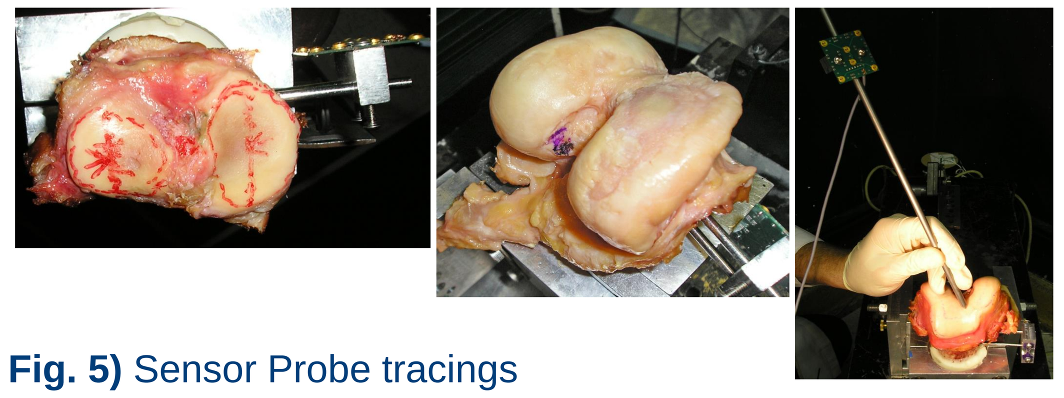

Fig. 5) Sensor Probe tracings (note origin and insertion of AM and PL bundles)

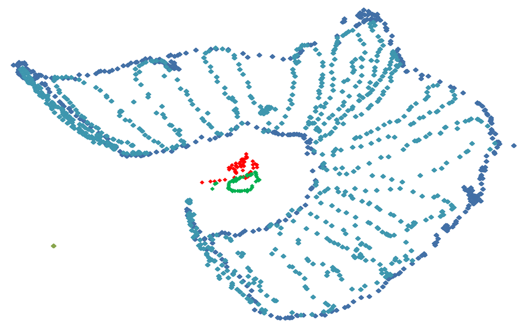

Fig. 6) Mapping of femoral joint surface. Red-AM origin, Green-PL origin, Turquoise- Femoral surface

Measurements & Data Analysis

- Quadriceps forces were measured with a Instron load cell in Newtons **(Fig. 3)**
- Three-dimensional tibiofemoral motion was described by determining screw axis parameters from the optoelectronic tracking data of the joint surfaces. **(Fig. 4)**
- Screw axis parameters were compared to evaluate changes in motion with flexion against increasing simulated eccentric quadriceps forces. This was done by taking sagittal cuts of the screw axes through the medial and lateral condyles **(Fig. 7,8)**
- Changes in ACL bundle length and strain were determined from the optoelectronic tracking data of the ACL origin and insertion sites. **(Fig. 6)**

Results: Knee Motion (Screw Axis)

- From full extension to 40 degrees of knee flexion, the sequential screw axis parameters of the medial and lateral condyle of the knee moved anterior as the eccentric quadriceps force increased. **(Fig. 7,8)**

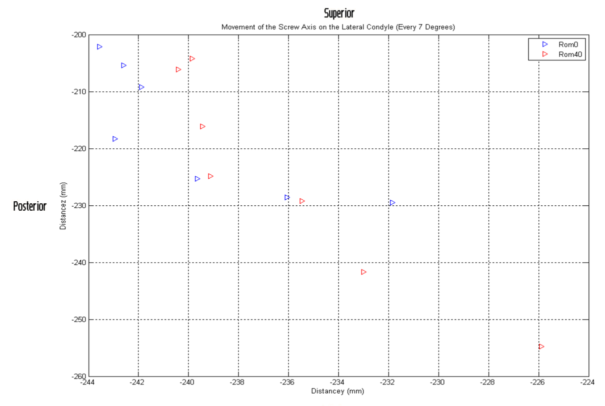

Fig. 7) **S**agittal cut through screw axes of lateral condyle. Note anterior position of red triangles (30 psi) in relation to blue triangles (0 psi).

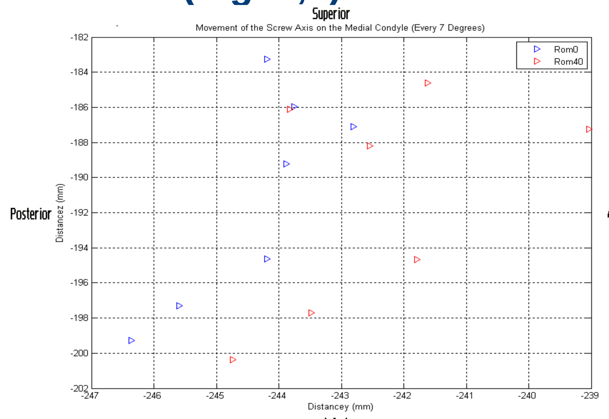

Fig. 8) Sagittal cut through screw axes of medial condyle. Note anterior position of red triangles (30 psi) in relation to blue triangles (0 psi)

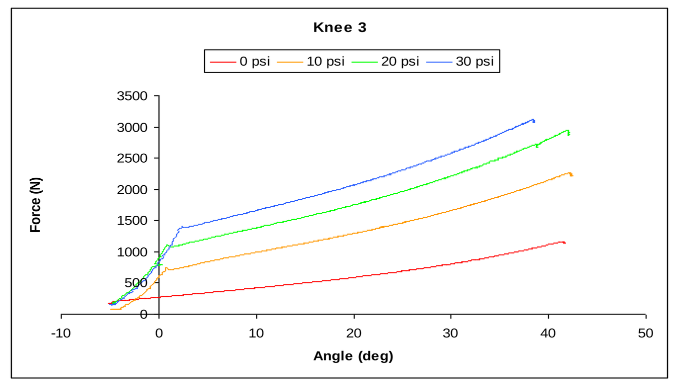

Fig. 3) Simulated eccentric quad forces

Results: ACL Strain (Anteromedial Bundle) (Fig. 9)

- With the largest eccentric quadriceps force applied, the strain of the **anteromedial** bundle of the ACL was minimal at full extension, increased to maximum at an average of 36.6 ± 7.1 degrees of knee flexion ($p<0.05$) and remained elevated with further flexion.
- This resulted in a peak strain of 0.049 ± 0.026.

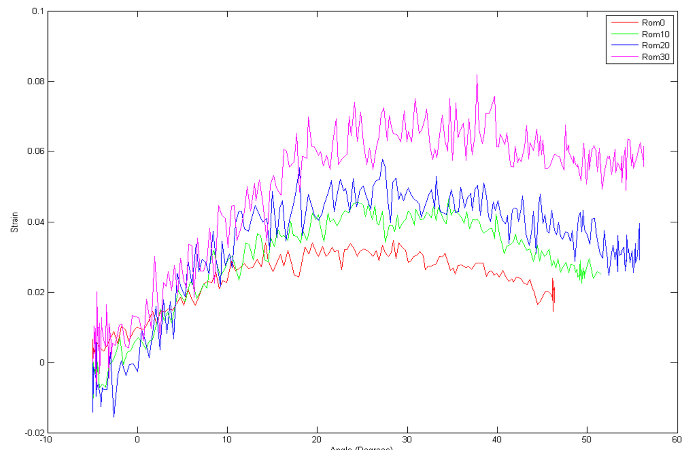

Fig. 9) Representative example of strain in AM bundle in knee 3

Results: ACL Strain (Posterolateral Bundle) (Fig. 10)

- With the largest eccentric quadriceps force applied, the strain of the **posterolateral** bundle of the ACL was elevated at full extension, increased to maximum at an average of 25.8 ± 7.3 degrees of knee flexion ($p=0.1$), and decreased with further flexion.
- The peak change in strain was 0.009 ± 0.035 (Figure 6).

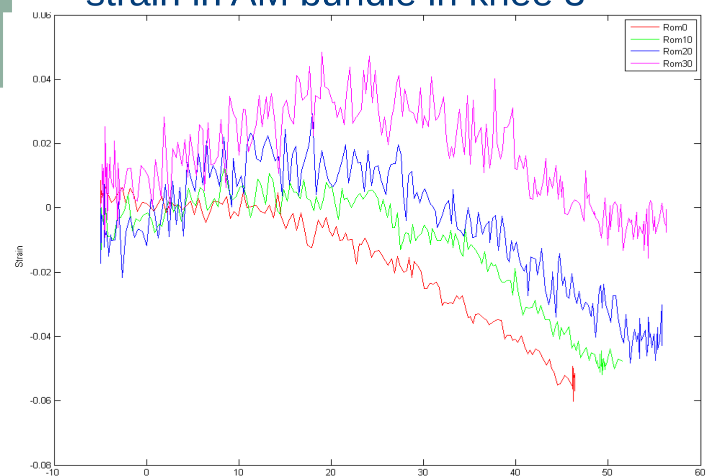

Fig. 10) Representative example of Strain in PL bundle in knee 3

Discussion

- The sequential screw axes moved anterior in the lateral and medial condyles as the knee was flexed against a simulated eccentric quadriqes force. This change in motion strained the AM and PL bundles of the ACL.
- The AM bundle of the ACL saw maximum strain at 36.6 ± 7.1 degrees with flexion against a large simulated eccentric quadriceps force. The PL bundle was stressed at lower degrees of knee flexion (25.8 ± 7.3) than the antermedial bundle.
- Sequential screw axis parameters can be used to evaluate the complex motion of the knee joint. These parameters describe rotation and translation of a rigid body in three dimensions and can be used to analyze changes in motion under simulated muscle forces.
- This new biomechanical model used customized optoelectronic sensors and a sensor probe to provide a non-invasive way of evaluating the function of ligaments during knee motion under simulated muscle forces.

ORTHOPAEDIC SURGERY AND SPORTS MEDICINE TEACHING AND RESEARCH FOUNDATION

1870 AD · MAIOREM · DEI · GLORIAM LOYOLA UNIVERSITY MEDICAL CENTER

Hinsdale Orthopaedics